

Portfolio Analysis and Management for Naval Research and Development



Richard Silberglied • Lorrie Sherry • Carolyn Wong • Michael Tseng
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Portfolio Analysis and Management for Naval Research and Development

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Preface

The Operations Analysis Program of the Office of Naval Research (ONR) sponsored this work to apply a research and development (R&D) portfolio management decision framework recently developed by the RAND Corporation to the evaluation of ONR applied research projects. This framework computes the *Expected Value* of an R&D project as the *product* of three factors: value to the military of the *capability* sought through R&D, the extent to which the *performance potential* matches the level required to achieve the capability, and the project's *transition probability*. The objective of the framework is to maximize the benefit of R&D spending in the presence of uncertainty inherent to R&D. The objective of this project was to demonstrate the framework through a case study evaluation of sample ONR Code 31 (Information, Electronics, and Surveillance Department) projects in command, control, and communications.

This report should be of interest to all stakeholders in the Navy R&D process, as well as R&D sponsors and managers throughout the military and civilian sectors.

This research was conducted for ONR within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally-funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the unified COMMANDS, and the defense agencies.

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Contents

Preface.....	iii
Figures	ix
Tables.....	xi
Summary.....	xiii
Acknowledgments	xix
Abbreviations	xxi
CHAPTER ONE	
Introduction	1
ONR Responsibility for Three Different Navies	1
The Challenge of Use-Inspired Basic Research.....	2
The Challenge of Facilitating Transition	2
Closing the Basic Research-Technology Development Gap with 6.2 Research.....	2
The RAND PortMan R&D Portfolio Management Decision Framework	5
Unique Aspects of the RAND Decision Framework.....	6
Using Expert Judgment to Estimate the Expected Value Components	7
Role of USNR on the Project Team.....	7
Outline of the Report.....	8
CHAPTER TWO	
Background	9
Department of the Navy 6.3 Review	9
The ONR Code 31 Program Evaluation Process.....	10
Related R&D Evaluation Approaches.....	12
CHAPTER THREE	
Methods.....	14
Overview of the RAND PortMan Portfolio Management Decision Framework	14
Capability	16

Performance Potential	17
Transition Probability	17
Value Descriptions and Scales	17
Data Requirements	20
Overview of the RAND E-DEL+I Technique and Process.....	22
Comparison of E-DEL+I and Traditional Consensus Building Methods	23
The E-DEL+I Process.....	23
Previous RAND Experience Using the E-DEL+I Method	25
CHAPTER FOUR	
Case Study Description	27
Composition of the Expert Panel.....	27
The Sample ONR Code 31 6.2 Research Projects.....	27
The Assessment Dimensions.....	28
The Assessment Questionnaire	29
General Info	29
Relevance.....	29
Applicability	30
Achievement	30
Conditions.....	30
Status.....	30
Implementability	30
Summary	30
Reference	30
Feedback.....	30
Rd XText.....	31
Dynamics of the Evaluation	31
Expert Panel Concerns and Final Assessments.....	32
Summary of Consensus Positions.....	33
CHAPTER FIVE	
Analysis of the Case Study Results.....	36
Expected Value Ranges of the Projects.....	36
The Components of Expected Value.....	38
Capability versus Performance Potential.....	38
Capability versus Transition Probability	41
Performance Potential versus Transition Probability	42
Demonstration of a Portfolio Analysis	44
CHAPTER SIX	
Conclusions and Recommendations.....	51

Contents vii

Appendix A. DoD Definitions of R&D Categories	55
Appendix B. The Island Defense Scenario	57
Appendix C. Value Descriptions and Scales.....	62
Appendix D. Project Summary Format	65
Appendix E. Project Overviews	66
Bibliography.....	73

Figures

S.1	Portfolio View of Case Study Evaluation Results	xv
1.1	Schematic View of the Transition from Basic Research Investment to Meeting Navy and Marine Corps Requirements.....	3
1.2	Schematic View of the Navy R&D Process.....	4
3.1	Portfolio View of the RAND PortMan Decision Framework.....	15
3.2	E-DEL+I Consensus Formation Process	24
4.1	Screenshot from E-DEL+I Excel Workbook	31
4.2	Modes and Consensus Positions for Capability/Relevance	34
5.1	Expected Value Ranges of the Case Study Projects.....	37
5.2	Capability versus Performance Potential	39
5.3	Capability versus Performance Potential with Uncertainty.....	40
5.4	Capability versus Transition Probability.....	42
5.5	Performance versus Transition Probability (versus Fig 5.4)	43
5.6	Expected Value Portfolio Analysis by Quadrant	44
5.7	Expected Value Portfolio Analysis by Grouping	46
5.8	Range of Uncertainty for Group 1	47
5.9	Range of Uncertainty for Group 2.....	47
5.10	Range of Uncertainty for Group 3.....	48
5.11	Range of Uncertainty for Group 4.....	48
5.12	Range of Uncertainty for Group 5	49

Tables

3.1	Capability.....	18
3.2	Performance Potential.....	19
3.3	Transition Probability.....	19
3.4	Capability Scale.....	20
3.5	Performance Potential Scale.....	20
3.6	Transition Probability Scale	20
3.7	Project Summary Format.....	21
4.1	Representation of Navy E-DEL+I Panel of Experts.....	28
4.2	Case Study Project Titles and Abbreviations	29
4.3	Summary of Consensus Positions of the Expert Panelists.....	35

Summary

The Office of Naval Research (ONR) has the responsibility for defining and sponsoring research and development (R&D) necessary to support both the current and future requirements of the Navy and Marine Corps. To accomplish this mission ONR must fund a broad spectrum of research, ranging from basic research needed to open up new options for the long-term, to very near-term advanced technology development to support the current fleet. Moreover, ONR must make its R&D funding decisions *in the presence of uncertainty*: uncertainty in required capabilities, uncertainty in performance requirements, and uncertainty in the feasibility of a technology or R&D approach.

This report describes the adaptation of an R&D portfolio management decision framework recently developed by RAND (Silbergliitt and Sherry, 2002), PortMan, to support ONR's R&D decision-making, and the demonstration of its use via a case study evaluation of 20 sample ONR applied research projects.

RAND's PortMan R&D Portfolio Management Decision Framework

RAND's PortMan R&D decision framework computes the *Expected Value*¹ of an R&D project as the *product* of three factors: value to the military of the *capability* sought through R&D, the extent to which the *performance potential* matches the level required to achieve the capability, and the project's *transition probability*. A useful interpretation of this equation is that the performance potential (i.e., the performance level that would be achieved if the project were successful), *scales* the capability value that is based on achieving a required level of performance. That scaled capability is then further reduced by the transition probability in order to obtain the *expected* value of the research, including its subsequent R&D stages and the fielding of the resulting process, component, or system.

¹ The equation for Expected Value used in PortMan is based on an adaptation of Decision Theory (see, e.g., Raiffa, 1997) as described in detail in Silbergliitt and Sherry (2002).

PortMan does not rely on the expected value as a point solution. Rather, it includes an estimate of uncertainty, and evaluates and compares R&D projects based upon all three components of the expected value, including uncertainty, plus their estimated direction of change over time. This requires evaluation based on best current information, and tracking over time as conditions change and the technology matures.

We note that the purpose of PortMan is to evaluate a defined group of actual or proposed projects and to provide a means for creating a portfolio from them that maximizes the value of R&D investments. It does not generate an absolute score for the total portfolio that could be used to compare to portfolios of other projects or to proportionally allocate funds between portfolios of different projects.

An important feature of this approach is that it allows identification of those R&D projects seeking high-value capabilities, but with formidable technical or fielding problems remaining to be solved, and for which management attention may have the greatest leverage.

The case study application of PortMan used RAND's E-DEL+ITM collaborative consensus building method (Wong, 2003) with an expert panel of Naval officers and senior civilian executives. This method retains the independent assessment features of the traditional Delphi method (Dalkey, 1969), and adds a teleconference between the participants to provide verbal feedback, in addition to the traditional written feedback. This case study evaluation was conducted via email and teleconference between participants in California, Rhode Island, Virginia, and Washington, D.C.

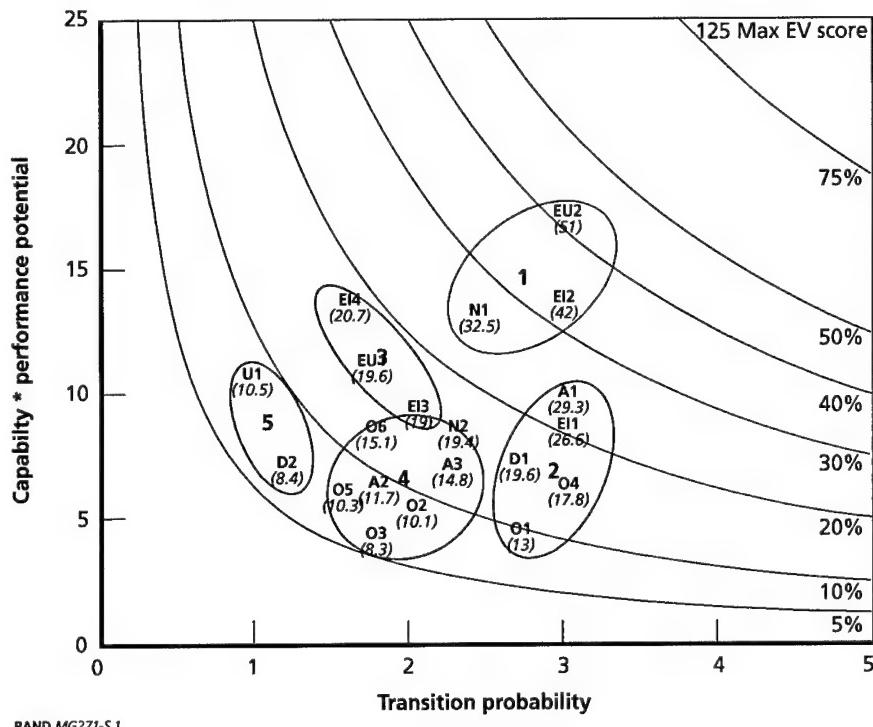
It is important to keep in mind that the evaluation described in this report is only a case study application of the RAND PortMan R&D portfolio management decision framework. As such, it was performed within the time and budget constraints of the project and should not be regarded as a complete or accurate evaluation of the 20 sample R&D projects evaluated. It is, however, valid as a case study demonstration of the use of the framework, because all of the evaluators had exactly the same data on which to base their evaluations, and the RAND E-DEL+I consensus generation method was consistently applied using the decision framework's anchored scales, together with a representative and well-qualified expert panel.

Portfolio Analysis and Investment Strategy

Figure S.1 summarizes the results of the case study evaluation of 20 sample ONR applied research projects. It plots the product of the mean values, as determined by the expert panel, of capability and performance potential versus the mean values of transition probability. The expected value for each project is shown in parentheses next to its data point. Contours of equal expected value are shown as a percentage of the maximum expected value.

This method of combining the components of expected value provides a convenient way to identify R&D projects with similar characteristics from an investment

Figure S.1
Portfolio View of Case Study Evaluation Results



strategy perspective. For example, consider the groupings shown in Figure S.1. Group 1, the highest on both axes, are the projects that are most likely to provide high-value capabilities that can be transitioned to use by the Navy. Group 2 are projects that are likely to be transitioned, but, because of their relatively low values on the y-axis, are also likely to provide only incremental improvements in current capabilities. Group 3 are projects with the potential to provide high-value capabilities, but which are not likely to transition without some changes to current approaches and plans. Group 4 are projects that appear to be aimed at incremental capabilities and do not have strong transition plans. Group 5 are projects that have not yet formed their transition strategies; one of these is aimed at a highly-valued capability, while the other is not.

As shown in Chapter 5 (see Figures 5.8 through 5.12), these project groupings are consistent with the uncertainty indicated by the spread of judgments obtained from the expert panel, in that the mean values for each group, plus the range of uncertainty, occupies a separate area of the plot.

The project groupings in Figure S.1 identify projects for which the R&D manager may have the greatest leverage. Consider, for example, the projects in Group 3, which are currently ranked relatively high in value and in the intermediate- to low-range in transition probability. In order to be successful, these projects will have to develop and implement a transition plan. We posit that, absent attention by the Program Manager,

the Principal Investigators may fail to do this within the time needed for a successful transition. Or, if they are not constrained sufficiently by floors on performance objectives, their tendency may be to seek out and pursue the easiest possible transition opportunities. This will increase their transition probability, but will likely happen at the expense of lowered performance objectives, which will move them toward (the incremental) Group 2 Management's job in this case is to provide the resources (e.g., staff, funds, facilities, information, coordination, planning) to overcome either of these tendencies and push the projects toward Group 1, as opposed to Group 2, maintaining or even improving the capability and performance potential objectives, while improving the transition prospects. Chapter 5 suggests the following set of steps to develop an investment strategy that can accomplish this task.

1. Review the data, consider the reasons for large uncertainties and outliers, and note any effects on project positions;
2. Give a high priority to providing sufficient resources for each Group 1 project to achieve its objectives;
3. Review the transition plans of the projects in Group 2 and allocate funds based on the relative importance of their capabilities, based on user inputs;
4. Review the technical approach and objectives of the projects in Group 3, then provide the resources to develop and implement transition plans that will allow the achievement and fielding of their identified capabilities;
5. Look for additional opportunities for projects in Groups 4 and 5 that have highly valued capabilities and for which the same approach as above in 4 can be pursued.
6. Fund remaining Group 4 and Group 5 projects based on the value of their capabilities, if and only if a sound case can be made for their moving into Group 2 on a specific time frame consistent with program objectives.

Since R&D decisions are made under uncertainty, it is critical to periodically reconsider the analysis and decisions based on the latest and best updated available data. In this sense, the S&T metric of RAND's PortMan decision framework is the position of each project on the chart of Figure S.1, together with its uncertainty, monitored over time. As the framework is repeatedly used, and the steps above repeatedly performed, this metric, and estimates of its direction of motion, will constitute a dynamic means for maximizing the leverage of program funds to develop and transition highly valued capabilities. We note that when using this metric, it is crucial to either continue with substantially the same expert panel, or to use a control group or perform a detailed analysis of variation to ensure that changes in the evaluations result principally from changes in the projects or the requirements and not from changes in the panel.

Conclusions and Recommendations

As described in detail in Chapters 1–5, RAND successfully adapted PortMan from civilian to military use. The case study evaluation demonstrated the use of the framework to develop and analyze the data needed to perform an R&D portfolio analysis and develop an R&D investment strategy, including uncertainty.

This framework can be used with an expert group determining the values of capability, performance potential, and transition probability, including uncertainty. In the case study evaluation, this was accomplished with RAND's E-DEL+I consensus building method.

The framework is capable of comparing and contrasting individual and groups of research projects as a function of key management variables such as their potential value and status and quality of transition planning. It also provides a straightforward and logical set of repeatable steps, (as described in Chapter 5) based on auditable data (e.g., developed for the case study as described in Chapter 4), to determine the expected value of research projects, together with a measure of uncertainty.

The framework provides a set of parameters for each research project (capability, performance potential, transition probability) that, together with measures of their uncertainties, form a metric that can be monitored over time as the framework is applied iteratively.

Based on the success of the case study evaluation, and the illustrations of its use for portfolio analysis and investment strategy development presented in Chapter 5, we recommend that ONR take the next step of demonstrating the framework on a specific project portfolio.

One possibility might be to incorporate the framework into an existing project review process, such as that currently used by ONR Code 31, as described in Chapter 2. In this case, capability value scales would be based on a group of scenarios or mission capability packages identified in collaboration with ONR Code 31, the value determinations would be made by the existing Code 31 expert panel, and the data for the evaluation would be presentations and background material prepared by the Program Managers and Principal Investigators. The panel evaluation could follow its current open meeting consensus-building approach, or use a Delphi-type consensus-building method such as RAND's E-DEL+I that was used in this project. RAND would then compile the data and develop and analyze the portfolio charts.

Another possible implementation of this decision framework might be to evaluate specific ONR project portfolios on a periodic basis by a standing expert panel, (e.g., appointed to staggered three-year terms with one-third of the panel new each year). The RAND E-DEL+I consensus building method might be used to structure the panel's deliberations together with the RAND PortMan decision framework used to perform a portfolio analysis and develop an investment strategy, in a fashion similar to that described in Chapters 4 and 5.

This application of the decision framework could be accomplished with a first round by email, and the additional rounds during a one-day or two-day meeting at which the data on capability, performance potential, and transition probability would be developed and plotted on the portfolio chart. The panel could then debate both the position of the projects on the portfolio chart and the likely direction of motion. Feedback could be provided to the ONR Program Managers and Principal Investigators concerning where they were placed on the chart and why.

This standing panel meeting could be used as a tool to redirect funding towards the most promising projects, with the data and analysis updated at each meeting. A note of caution: successful R&D projects take time, so one would not expect to see wholesale changes in funding. Perhaps projects might be reviewed on a yearly basis, and funding changes made only after multiple unsatisfactory reviews. Such yearly reviews could enable ONR management to emphasize higher payoff R&D, and to track progress towards achieving needed performance, as well as responding to changing requirements in a timely fashion, consistent with sound R&D management practices. Whether it is applied to a subprogram, program, or entire class of projects (e.g., 6.2, applied research, or 6.3, advanced technology development), RAND's PortMan decision framework can be tailored both to the scope of the evaluation and to the available resources. Projects can be evaluated in groups to achieve the desired number of individual units for the evaluation. The amount of data used in the review would then be the maximum consistent with the resources available for the evaluation.

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We extend our sincere thanks to the members of the expert panel of the case study evaluation described in Chapter 4, who responded to our assessment questionnaires with dispatch and intelligence, within tight deadlines. We also commend the panel on their collegiality and their excellent questions on and critique of the assessment approach and the data provided, which we will take as direction to improve the process. Thanks are also due to Irv Blickstein for his excellent facilitation of the expert panel teleconference session. The members of the expert panel were: Philip DePoy (Naval Postgraduate School), CAPT Chris Earl (DARPA), CDR Mike Hajosy (NET-WARCOM), CAPT Scot Miller (Naval Systems Interoperability Center), CAPT John Meyer (Naval War College), Alan Shaffer (OSD), and Frank Shoup (OPNAV).

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Abbreviations

A1-3	Alternative Human-Machine Interface Projects 1–3
AAW	Anti-aircraft Warfare
ADNS	Automated Digital Network System
AOP	area of probability
ASCM	antiship cruise missile
C2	command and control
C2CS	Command, Control, and Combat Systems
CEP	Cooperative Engagement Processor
CJTF	Commander, Joint Task Force
CNO	Chief of Naval Operations
COP	common operational picture
CTP	Common Tactical Picture
CVBG	carrier battle group
D&I	discovery and invention
DAB	Defense Acquisitions Board
DARPA	Defense Advanced Research Projects Agency
DISN	Defense Information Systems Network
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DoN	U.S. Department of the Navy
D1-2	Distributed Sensor Fleet Projects 1–2
E-DEL+I	(RAND’s) Electronic Decision Enhancement Leverager Plus Integrator
EV	Expected Value
EI1-4	Expeditionary Communications Infrastructure Projects 1–4
EU1-2	Expeditionary Communications Upgrade Projects 1–2
FNC	Future Naval Capability

FY	fiscal year
GPS	Global Position System
INS	inertial navigation system
IP	Internet protocol
IPT	Integrated Product Team
IPv4	Internet protocol version 4
IPv6	Internet protocol version 6
IRI	Industrial Research Institute
ISR	intelligence, surveillance, and reconnaissance
JCS	Joint Chiefs of Staff
JTRS	Joint Tactical Radio System
NCW	network-centric warfare
NETWARCOM	Naval Network Warfare Command
NISTEP	National Institute of Science and Technology Policy (Japan)
N1-2	Network/Information Infrastructure Projects 1–2
ONR	Office of Naval Research
ONR Code 31	ONR Information, Electronics, and Surveillance Department
O1-6	Optimization or Decision-Aid Projects 1–6
OPNAV	Office of the Chief of Navy Operations
OSD	Office of the Secretary of Defense
PEO	program executive office
PortMan	(RAND's) Portfolio Management (Decision Framework)
QoS	quality of service
RF	radio frequency
R&D	research and development
SLAM	standard land attack missile
SLOC	Sea Lines of Communication
SSN	submersible ship nuclear [attack submarine (nuclear propulsion)]
S&T	science and technology
UCAV	Uninhabited Combat Air Vehicle
UHF	ultrahigh frequency
USC	University of Southern California
USNR	U.S. Naval Reserve
U1	UAV General Research Project 1
V	volatility
v/c	value-cost ratio
6.1	basic research
6.2	applied research
6.3	advanced technology development

Introduction

This chapter briefly describes the responsibilities and challenges facing the sponsor of this study, The Office of Naval Research (ONR). It then briefly introduces RAND's Portfolio Management (PortMan) decision framework and explains how this approach is aimed at meeting ONR's challenges. The chapter concludes with an explanation of the role of U.S. Naval Reserve (USNR) officers in supporting this study and an outline of this report.

ONR Responsibility for Three Different Navies

The ONR has the responsibility for defining and sponsoring research and development (R&D) necessary to support the requirements of three different Navies and Marine Corps: the current Navy and Marine Corps, the Navy and Marine Corps of the next five years, and the "Navy and Marine Corps After Next" of perhaps 20 years into the future (Saalfeld, 2001, Gaffney et al., 2000). Since the R&D requirements of each of these Navies and Marine Corps are vastly different, ONR must fund a broad spectrum of research, ranging from 6.1 basic research, needed to open up new options for the long-term, to very near-term 6.3 advanced technology development to support the current fleet.¹ Moreover, ONR must make its R&D funding decisions in the presence of uncertainty: uncertainty in required capabilities, uncertainty in performance requirements, and uncertainty in the feasibility of a technology or R&D approach.

¹ Appendix A lists the current DoD definitions of the categories of R&D. ONR's responsibility is to sponsor 6.1–6.3, basic and applied research and advanced technology development, and to transition it to users and programs that sponsor and conduct 6.4 and higher levels of R&D leading to implementation. ONR is uniquely charged with responsibility for both Discovery and Invention (6.1 and most of 6.2) and Exploration and Development (the most mature part of 6.2 and all of 6.3). The spectrum of 6.1–6.3 R&D is defined as science and technology (S&T).

The Challenge of Use-Inspired Basic Research

To successfully execute its mission, ONR must pursue cutting-edge basic research in scientific areas that are of unique interest to the Navy, build on the basic research advances made by ONR and other organizations in areas of joint interest, and direct its applied research and technology development toward user requirements that will facilitate transition. Its basic research component thus cannot be only curiosity-driven, but must also be strongly driven by a sense of the potential use of new technological options and capabilities by the Navy and Marine Corps After Next. This “use-inspired” basic research combines the most rigorous approach to fundamental understanding with a strong focus on solving real-world problems, much in the spirit of Louis Pasteur’s groundbreaking R&D successes in biology and medicine (Stokes, 1997).

The Challenge of Facilitating Transition

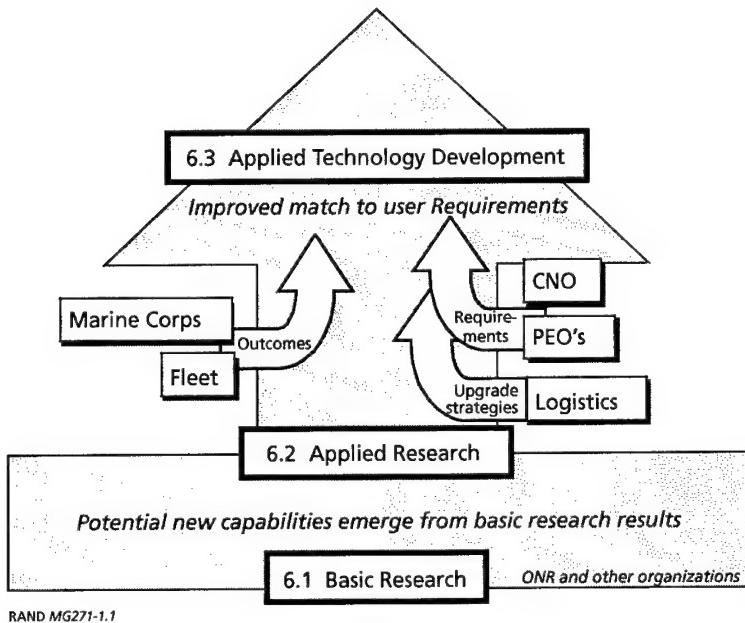
ONR’s challenge of facilitating transition is similar to that faced by commercial firms who often find that the exponential increase in funds required for product development, coupled with the lag in cash flow from sales, leads to a “valley of death” for many potential products that emerge from successful R&D programs. To overcome this challenge, ONR several years ago instituted the Future Naval Capabilities (FNC) program. FNCs have specific 6.3 objectives for enabling capabilities defined by Integrated Product Teams (IPTs), which include representatives from the science and technology (S&T), requirements, and acquisition communities. Contingent on meeting these 6.3 objectives, “spike” funding is committed, including 6.4 funds, to accomplish the transition.

Closing the Basic Research-Technology Development Gap with 6.2 Research

ONR’s R&D investment strategy must balance two sometimes competing roles: aligning priorities with user requirements to accomplish transition, while continuing to nurture and develop the S&T base that comes from use-inspired basic research. In this report, we will focus on the middle portion of ONR’s R&D spectrum (6.2), for it is here that the “rubber meets the road” in linking up the basic research advances of ONR and others with the Navy and Marine Corps user requirements that must be met in order to successfully transition technologies.

The Chief of Naval Research, RADM Jay M. Cohen, recently described ONR’s basic research investment strategy as “planting a thousand flowers, to get 100 projects,

Figure 1.1
Schematic View of the Transition from Basic Research Investment to Meeting Navy and Marine Corps Requirements

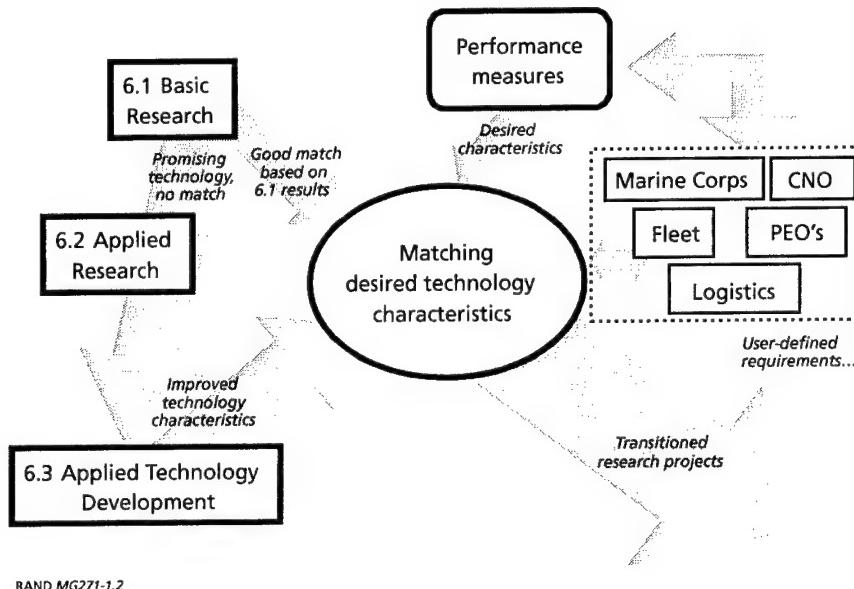


three prototypes, and one profit-maker.”² Our objective in this report is to describe an approach and a quantitative method for evaluating those flowers and projects, as they emerge, in order to develop investment strategies that can nurture and grow the most promising projects among them. This method must, and will, allow for periodic reexamination and reevaluation, as conditions change and the technologies mature, to sharpen the investment strategy and guide the projects to a successful transition that meets user requirements.

Figure 1.1 schematically illustrates the process via which advances resulting from basic research investments are built upon through 6.2 and 6.3 research to meet Navy and Marine Corps requirements. At the intermediate 6.2 stage the “market pull” requirements must be matched by building on the “technology push” from successful 6.1 research results. Our principal objective in this work is to provide a means for evaluating R&D investments in terms of their ability to facilitate this matching and thus close the gap between 6.1 research and Navy and Marine Corps requirements.

² Interview quoted in *Sea Power*, February 2004, p. 29. A detailed study of project literature, patent literature and experience, and venture capital experience (Stevens and Burley, 1997) validates this approach with industrial experience, suggesting that it takes 3000 new ideas to achieve one commercial success.

Figure 1.2
Schematic View of the Navy R&D Process



RAND MG271-1.2

Figure 1.2 schematically illustrates the process of matching the capabilities to be developed through R&D to those that meet end user requirements. To define these capabilities, we take a warfighting scenario approach. The benefit of such an approach is that one can readily identify which capabilities are useful to the scenario objectives, and even under some circumstances quantify performance levels required to achieve them. For example a recent RAND report (Perry et al., 2002) describes an island nation defense scenario and related measures of effectiveness for technological performance based on achieving the scenario objectives.³

The process for which we wish to develop a sound investment strategy is the matching of the performance of technologies that emerge from 6.1 research to the performance needed to meet the requirements for capabilities that will perform in Navy and Marine Corps mission-critical scenarios. We note that the 6.1 base on which the R&D advances are built is the combined result of research sponsored by ONR and other agencies. In certain cases, these results are already a close enough match that they can directly transition (e.g., signal processing algorithms that may be directly adopted by industry). On the other side of the spectrum are 6.3 projects that work with already mature capabilities to facilitate the transition to 6.4 and higher levels of R&D. The

³ We adopted this scenario as a concrete example within which to initially evaluate capabilities proposed for development through R&D for the case study. The downside of this approach is that there are many more warfighting scenarios that may be equally as important as or even more important than this island scenario. As described below in the methods chapter, we sought to balance the scenario approach by including two components in the estimate of capability value, the first dependent upon usefulness in the island scenario, and the second dependent upon breadth of usefulness in a range of scenarios identified as important by the Navy.

focus of this report is on those capabilities that are not yet mature, and for which 6.2 projects may improve the match sufficiently to reach a level of attractiveness to the end users that can effectively bridge the “valley of death” alluded to previously.

The RAND PortMan R&D Portfolio Management Decision Framework

This section describes RAND’s PortMan R&D decision framework. We note that the purpose of PortMan is to evaluate a defined group of actual or proposed projects and to provide a means for creating a portfolio from them that maximizes the value of R&D investments. It does not generate an absolute score for the total portfolio that could be used to compare to portfolios of other projects or to proportionally allocate funds between portfolios of different projects.

RAND’s PortMan R&D decision framework (Silbergliitt and Sherry, 2002) approaches the R&D investment strategy problem by evaluating the expected value (EV) of each R&D project based upon the answers to three fundamental questions:

1. What is the value to the end-users of the capability, at a specified performance level, that the R&D is aimed at achieving?
2. What is the potential of the R&D, if successful, to achieve the performance level required for this capability?
3. What is the probability that the R&D approach will be successful and will be transitioned and fielded?

The EV is computed as the product of capability, performance potential, and transition probability.⁴ Thus performance potential and transition probability become *scale factors* that *reduce the value* of the capability that would be achieved with full performance and project transition and fielding. It is this scaling of value, plus the portfolio analysis methods described in Chapters 3 and 5, which define the PortMan approach. PortMan can be applied with scenario-based capability values, as in the case study described in Chapters 4 and 5, or any alternative valuation method.⁵

The answers to the above questions depend on experts’ estimates of: (1) the value to the Navy and Marine Corps of meeting specific requirements; (2) the potential for achieving specific levels of performance; and (3) the quality of transition planning and activities. All of these quantities may change over time. Effective use of this framework

⁴ The equation for Expected Value used in PortMan is based on an adaptation of Decision Theory (see, e.g., Raiffa, 1997) as described in detail in Silbergliitt and Sherry (2002).

⁵ A notable approach for value estimation is described in Saunders et al., 1995, which uses 2-D plots of relative value versus breadth of demand to determine the value to the Navy of specific capabilities. PortMan provides a way of evaluating the extent to which R&D on specific projects might achieve the level of performance necessary to achieve these capabilities.

depends on: collecting the best available data on requirements, performance potential, and transition planning and activities for each project; integrating the judgments of the best available experts based on these data; and repeating the process at reasonable intervals to support a dynamic investment strategy that takes advantage of emerging opportunities.

The use of PortMan to analyze a project portfolio and develop an investment strategy, as described in Chapters 3 and 5, draws on a number of approaches that have been described in the industrial research management literature (see, e.g., Cooper et al., 1997). As noted by Cooper et al., portfolio management has three broad goals: value maximization; balance; and strategic direction. PortMan maximizes the value of the portfolio by computing and analyzing the components of EV for each project (see, e.g., Figures 5.1 through 5.7). It allows explicit comparisons of project characteristics that allow the manager to balance the portfolio (e.g., as concerns risk versus reward). Finally, it allows development of an investment strategy for *this portfolio* that is explicitly aimed at achieving capabilities that reflect the strategic needs identified in the scenarios (or other means) used to define warfighter value.

Unique Aspects of the RAND Decision Framework

We note here two principal differences between this approach and the conventional evaluation of R&D projects: (1) the EV is a product, not a weighted sum of factors; and (2) there is an uncertainty range, not a point solution. Elaborating on point (2), we do not propose to use the EV as the sole benchmark for comparing projects. Rather, we will evaluate and compare R&D projects based upon the three components of the EV, including uncertainty, plus their estimated direction of change over time. The investment strategy question then will be: How will my investment of \$X in this project cause these quantities to change and how much is that change worth? Returning to the flower analogy of the previous section, we want to provide the nurturing and support that will allow the most promising buds to bloom and prosper. As discussed in Chapters 3 and 5, the analysis provided by using this framework will allow the development of investment strategies tailored to the strengths and weaknesses of specific research projects.

There is a strong similarity here to recent work in the financial options arena (Luehrman, 1998) in which options are viewed as investments in a tomato garden. You never want to invest in rotten tomatoes (low on all components of EV) and you always want to invest now in ripe tomatoes (high on all components of EV). The challenge is to figure out how and when to invest your limited resources on the tomatoes in between (i.e., how to pick the options that are developing well enough so that with your help they become more likely to mature in your required time frame). Likewise, our problem is to identify the R&D projects that have sufficient promise that with investment, they may mature to meet requirements and be transitioned. This requires evaluation based on best current information, and tracking over time as conditions

change and the technology matures. Some of these projects will be of high value to the warfighter, but with formidable problems remaining to be solved. The question for these is: Can our investment move them into the promising and now ripening region of the tomato garden?

Using Expert Judgment to Estimate the EV Components

This case study application of RAND's PortMan decision framework used RAND's E-DEL+I™ collaborative consensus building method (Wong, 2003) with an expert panel of Naval officers and senior civilian executives. This method retains the independent assessment features of the traditional Delphi method (Dalkey, 1969), with each expert evaluating the capability, performance potential, and transition probability of the same 20 sample ONR applied research projects using the same data, and then reevaluating after receiving composite anonymous feedback showing how the other members of the panel evaluated the same projects. After these traditional first two rounds of Delphi evaluation are completed, E-DEL+I uses a teleconference between the participants to provide verbal feedback in addition to the traditional written feedback. Participants are not identified during the teleconference, which is facilitated by an independent expert and focuses on discussion of the questions on which the participants had the largest variation of responses in the first two rounds. In this way, E-DEL+I allows for a mix of written and verbal arguments, thus balancing between participants who are better at one medium or the other. The third evaluation round is performed during a break in the teleconference and the fourth after the teleconference is completed. Both of these rounds use the same independent and anonymous evaluation as the first two rounds, thus preserving one of the hallmarks of the traditional Delphi method. Finally, E-DEL+I has proven to be highly timely and cost-effective, since it is conducted via e-mail and teleconference, and hence does not require any travel. For example, participants in the exercise described herein were located in California, Rhode Island, Virginia, and Washington, D.C.

Role of USNR on the Project Team

RAND was supported in the work described in this report by officers of the USNR Program 38, assigned to ONR. The role of the USNR was principally in two areas: (1) definition of value to the warfighter; and (2) development of a plan for integrating the RAND PortMan decision framework into the overall Navy R&D decision-making process. In particular, USNR officers developed background information on the Navy's approach to S&T metrics, prepared the scenario description that was used by the expert panel in the Delphi evaluation of ONR applied research projects, assisted in the formation of the expert panel, and participated throughout the work in discussions between RAND and ONR staff.

Outline of the Report

The balance of this report is organized as follows: Chapter 2 provides background and information on current approaches within the Navy for R&D project evaluation and provides a context for the RAND PortMan decision framework in terms of other relevant decision-making aids. Chapter 3 summarizes the salient features of the two RAND methods used in this work—the RAND PortMan decision framework, and the RAND E-DEL+I consensus building method. Chapter 4 provides the details of the case study evaluation of 20 ONR Code 31 (Information, Electronics, and Surveillance Department) 6.2 R&D projects. Chapter 5 analyzes the results of the case study and discusses how to use such results to perform portfolio analysis and develop an investment strategy. Chapter 6 describes RAND’s conclusions based upon the case study results and RAND’s recommendations for the use of the decision framework for R&D portfolio analysis and investment strategy development. Five appendices provide additional details relevant to the material described in the text of the report. Appendix A lists the official Department of Defense definitions of the stages of research discussed throughout this report. Appendices B, C, D, and E provide background materials used in the case study evaluation.

Background

The portfolio management decision framework described in this report must operate within the context of existing Navy institutions and procedures. Prior to the initiation of RAND's work on adapting its framework for ONR, CAPT Aaron Watts (USNR) carried out an informal survey of how Navy and Department of Defense (DoD) organizations involved in R&D currently measure or evaluate their S&T investments. He found a highly eclectic mix of approaches, ranging from oral boards based on detailed written submissions, to computer-based tools that use specific anchored scales. The definition of measures of effectiveness and the data collection requirements to estimate these measures differed substantially between organizations, so comparison of the RAND approach to a "generic" Navy approach was not possible. However, two specific recent examples of Navy S&T evaluations provide a context for the present work.

Department of the Navy 6.3 Review

The Department of the Navy (DoN) recently performed an internal review of its entire Fiscal Year 2000 Advanced Technology Development (6.3) program (Kostoff, Miller, and Tshiteya, 2001). A 31-member panel, composed of senior Naval Officers and civilian executives drawn from ONR, The Marine Corps, the DoN S&T resource sponsor (Office of the Chief of Naval Operations, OPNAV 911), and operational Navy organizations responsible for setting requirements performed this review. The review panel was provided with data prepared and presented by 55 different programs, based on the taxonomy by which programs were selected and managed. The data were targeted toward a specific set of evaluation criteria: Military Goal (importance to each of 12 designated FNCs), Military Impact (potential for military capability improvement), Technical Approach (technical payoff versus alternatives), Program Executability (probability of demonstration), and Transitionability (probability of transition). Descriptions were provided for rankings of high, medium, and low for each of these criteria, as well as for an overall item evaluation (based on incremental versus revolu-

tionary improvement in military and technology capabilities). In addition to the 6.3 presentations, the panelists received situation report presentations from the Chairs of each of the FNC IPTs.

While the scope of this evaluation (55 programs averaging approximately \$10 million each) was far greater than that of our 20-project case study, there are some important similarities in approach. Both used a panel of senior Naval officers and civilian executives drawn from organizations with diverse perspectives. Both provided the panel with data targeted toward specific evaluation criteria based on importance of the capability to the Navy, potential to achieve improved capability, and probability of transitioning that capability to the Fleet. Both also provided value descriptions for their ranking scales.

However, there are some clear differences between the DoN 6.3 review and the application of the RAND PortMan decision framework to evaluate ONR applied research (6.2) projects. The DoN 6.3 review asked each panelist to assign a “bottom-line quality score” (Overall Item Evaluation). As briefly summarized in Chapter 1 and described in more detail in Chapters 3 and 5, RAND computes an EV as a product of the capability, performance potential, and transition probability scores of each panelist and accounts for uncertainty, not using a point solution. Furthermore, RAND performs a portfolio analysis using the range of capability, performance potential, and transition probability values assigned by the panelists. This reflects the differences in potential payoff and maturity of the projects, and allows comparative analysis of the possible leverage of R&D investment and management attention for individual projects, or groups of projects. Another difference of less significance is that RAND staff compiled the data for the evaluation based on proposal information provided by ONR. This was dictated by time and resource constraints. The RAND PortMan framework could certainly be used with data prepared and/or presented by Naval staff.

The ONR Code 31 Program Evaluation Process

The following description of the program evaluation process currently used by ONR Code 31 (Information, Electronics, and Surveillance Department) is a summary of an evaluation report written by CDR Vance Brahosky (USNR).

ONR Code 31 uses a program evaluation model based on a “Board of Directors” template. This model makes use of leaders drawn from the various research laboratories, acquisition program offices, Systems Commands, and OPNAV who meet, on an annual basis, in a technology review known formally as the “ONR 6.2 Review” and informally as “the Gathering.” During the course of this Gathering, current fiscal year Discovery and Invention (D&I) 6.2 programs are reviewed and next fiscal year D&I 6.2 proposals (new starts) are evaluated.

Dr. Bobby Junker, Head of Code 31, chairs the reviews conducted for each of the functional areas under his cognizance (Navigation, Electronic Warfare, Command and

Control, Electronics Technology, Surveillance and Communications). This is a phased review that dedicates separate time periods to focus on each of the six functional areas. Each area review is typically allotted between 3 and 5 days, with a review panel size between about 8 and about 18 individuals, depending on the scope of the program. Dr. Junker provides a framework for the decisionmaking process in the form of guidance that summarizes current Navy visions and strategy, identifies Code 31 priority technical areas and capabilities, and details the requirements for technical presentations. The basic data for the evaluation are presentations of the ongoing 6.2 programs and the proposed new 6.2 starts, which are made by the relevant Program Managers and Principal Investigators. To provide a perspective for the 6.2 review, relevant portions of the basic research (6.1) program and of the FNC programs are also presented to the panel.

The Code 31 program evaluation process uses a prescreening of solicited white papers from laboratories and warfare centers to select those new start proposals to be submitted to the panel review at the Gathering. This prescreening process uses a three-person panel of ONR program managers (which we call the “prescreening panel” to differentiate it from the review panel at the Gathering) to evaluate the white papers. The prescreening panel members evaluate each white paper on *subjective* 1–10 scales for each of two criteria: “S&T Technology Value” and “Transition Potential.” The scores on each of these criteria are added together to get a total score, and each member of the prescreening panel provides a priority order based on their total scores for each white paper. The prescreening panel then meets as a group and puts together a consensus priority list. The new start proposals that are presented at the Gathering are based on the white papers that came out on top on the prescreening panel consensus priority list. The number varies between programs, but is typically larger than can be funded with the projected fiscal year new start budget.

During the Gathering, the review panel scores each new start proposal, as it is briefed, and turns in a completed score sheet at the end of each briefing. The evaluation criteria are: (1) Technical Rationale (i.e., will success of this project have a significant impact on the scientific and technical state-of-the-art), (2) Department of the Navy Rationale (i.e., what DoN critical need is addressed by this effort), and (3) Programmatic Rationale (i.e., why is now the right time to do this work). These score sheets are compiled and used as the basis for a final panel review meeting that is held at the conclusion of the Gathering. At this final review meeting, the panel develops and submits to Code 31 a consensus list of priority recommendations for new starts.

Like the DoN 6.3 Review, the ONR Code 31 6.2 evaluation process bears some similarities to the RAND PortMan decision framework. It uses a broadly based expert panel to perform the evaluation and bases the evaluation on data that are targeted toward specific evaluation criteria related to value of capabilities to the Navy, technical performance, and transition probability. However, there are also some important differences. While the Code 31 process uses specific evaluation criteria, it bases its

evaluations on subjective scores, not anchored scales with specific value descriptions. Also, like the DoN 6.3 review, the Code 31 process uses a point solution,(i.e., a single numerical priority ranking of projects), whereas, as noted above, RAND computes an EV and performs a portfolio analysis, including estimates of uncertainty in capability, performance potential, and transition probability. Finally, the Code 31 process uses presentations to provide the evaluation data, whereas in the case study evaluation RAND compiled project summaries based on the proposal data. As noted above, this was dictated by time and resource constraints. The RAND PortMan framework could certainly be used with data prepared and/or presented by Program Managers and Principal Investigators.

Related R&D Evaluation Approaches

Two key features of this RAND approach are its use of anchored scales (i.e., scales that include explicit descriptions of the requirements or thresholds for assigning particular values) and its recognition of uncertainty in the estimation of the components of the EV: capability, performance potential, and transition probability.

Anchored scales have recently been used by the Industrial Research Institute (IRI) (Davis et al., 2001) to develop a method for estimating the probability of success of commercial R&D. Technical factors were proprietary position, competencies, complexity, access to technology, and manufacturing capability. Commercial factors were market need, brand recognition, distribution channels, customer strength, raw materials, and safety, health, and environmental risks. For each factor, the authors wrote a description characterizing rankings of 1 through 5. These scales were then used by an IRI committee to evaluate a specific business opportunity.¹ The use of the anchored scales led to explicit recognition of *not only the pros and cons of the opportunity, but also the reasons for them*. This allowed a dialog between committee members on whether or not to pursue the opportunity now, and how to improve its chances for success in the future.

The RAND PortMan decision framework uses anchored scales in a similar fashion. By requiring the evaluators to answer specific questions concerning capability, performance potential, and transition probability, this RAND framework collects and records the information needed to analyze the positive and negative aspects of each R&D project, and to facilitate discussion and analysis of possible investment strategies.

R&D is by its nature performed in the face of uncertainty. The reason for pursuing the R&D effort is to increase knowledge and capability in a way that enables new approaches, processes, and technologies. But there is always the risk that the R&D will fail to meet its objectives. R&D investment strategies thus attempt to balance this risk

¹ This was a realistic example constructed for the analysis, not an actual opportunity.

against potential payoff. Because it is possible to cancel unsuccessful projects before they reach the most expensive (product development) stage, it has in fact been argued based on analysis of the earned value of R&D that projects with higher risk and higher payoff are preferred (Morris, Teisberg, and Kolbe, 1991).

The R&D investment decisions we are considering in this report are not one-time actions, but rather steps along a particular technology or capability development path. At each stage along this path, the investment decision will be reviewed and revisited, as more information becomes available, both through the R&D results and through external events, including the R&D and technology development of others. In this sense the EV we compute using the RAND PortMan decision framework is really a *prospective* value, because it is based on best estimates, using current data, of future capability, performance potential, and transition probability. Thus the decision to fund an R&D project can be viewed as a decision to invest in an option—to perform the R&D and thus gain the knowledge to make a more informed decision at a later date.² In fact, there is precedent in the commercial sector for the valuation of R&D investments using financial options approaches (Faulkner, 1996).

As described by Luehrman, 1998, one can characterize investment opportunities in terms of their potential value-cost ratio (v/c), and volatility (V). High v/c with low V means invest now. Low v/c with high V means invest probably never. The difficulty comes when V is large, but so is v/c . For R&D, these are the potentially high-payoff, but also high-risk, investments. Luehrman suggests following the change over time of v/c and V on a 2-D graph and making those investments that are moving into the upper v/c , lower V quadrant. For R&D investments, this means funding those R&D projects aimed at high-value capabilities but with remaining technical or other problems, then tracking over time how well the problems are being solved and whether or not the value of the capabilities has changed. This is precisely what the RAND PortMan decision framework does with its portfolio chart, as described briefly in Chapter 1 and in greater detail in Chapters 3 and 5.

² The authors are indebted to Steven Popper for elucidating the points made in this paragraph.

Methods

This chapter describes the two methods used in this work: the RAND PortMan R&D decision framework, adapted to provide an R&D investment strategy method for the Navy; and the RAND E-DEL+I consensus building method, used to perform a case study application of this decision framework to 20 ONR Code 31 6.2 projects, using an expert panel.

Overview of the RAND PortMan Portfolio Management Decision Framework

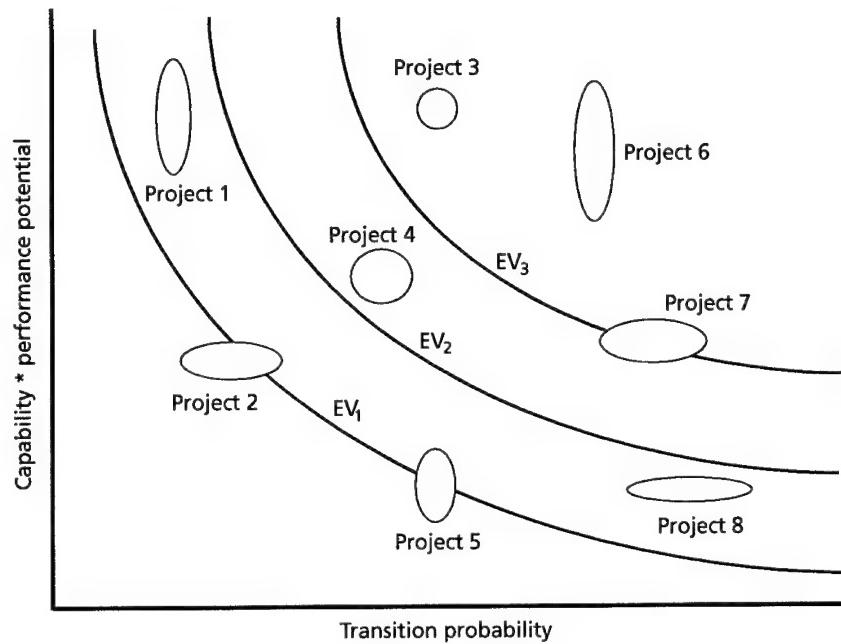
As noted previously, the RAND PortMan decision framework computes an EV for each R&D project as the product of capability, performance potential, and transition probability. However, this scalar quantity combines several important aspects of each project. In order to analyze the R&D portfolio, we recommend plotting a graph such as the one shown in Figure 3.1, which also takes into account the uncertainty in the evaluations of the EV components.

In Figure 3.1, the x-axis is the transition probability, the y-axis is the capability times the performance potential, the points represent the average of the values assigned by the evaluators for each R&D project, using anchored scales as described below, and the circles or ovals around the points indicate the spread of assigned values for each project.¹ Constant EV contours are hyperbolae on this graph, as indicated in the figure, with increasing EV as both x and y increase.

Figure 3.1 provides a visualization of the R&D portfolio that facilitates comparisons between the projects and identification of investment opportunities with maximum leverage. For example, Projects 3 and 6 are clearly good investments—highly valued capabilities with good transition probability. Project 8 is very likely to be tran-

¹ We note that these values are subjective estimates of expert evaluators, based on best available data, and tied to explicit anchored scales.

Figure 3.1
Portfolio View of the RAND PortMan Decision Framework (after Silbergliitt and Sherry, 2002)



RAND MG271-3.1

sitioned, but will provide a much less important, more incremental, capability. Project 1 is an example of a highly valued capability that currently has a very low transition probability. The question to ask here is whether or not, with investment and management attention, the technical and fielding problems that led to the low transition probability can be solved without giving up the performance potential that led to the high value.

In other words, the plot has identified Project 1 as a potential opportunity that requires management attention and has possible high payoff. If it continues without management attention, this project might fail to develop and execute a successful transition plan within the necessary time. Or, if it is not constrained sufficiently by floors on performance objectives, it might just seek out and pursue the easiest possible transition opportunity, providing an incremental performance improvement rather than the more likely transformational one that led to its current position on the plot. Similar analysis should be performed for the other projects, comparing them and grouping them in terms of potential payoff and investment and management leverage. An example of such an analysis is shown in Chapter 5 for the case study evaluation of the 20 sample ONR 6.2 projects.

It is important to note that both the average values and the uncertainties of the R&D project portfolio are dynamic quantities that may change over time as a result of technical results and programmatic and institutional changes. The RAND decision

framework provides a means for periodic reevaluation of the R&D projects and tracking and monitoring of the R&D portfolio over time. The combination of capability, performance potential, transition probability, and their variations with time then provides a multidimensional science and technology (S&T) metric. This metric is defined through a transparent, logical, auditable process using expert evaluations based upon defined data and anchored scales. It also forms the basis for a time-dependent portfolio analysis that is actionable, fulfilling a strong recommendation that emerged from the DoN Fiscal Year 2000 6.3 review (Kostoff et al., 2001, p. 295). The following text describes the approach that RAND took to evaluate each of the EV components, and discusses the anchored scales developed for the evaluation, including their data requirements.

Capability

In the prior application of this framework for the Department of Energy (Silbergliitt and Sherry, 2002), capabilities sought through materials R&D were valued in terms of their potential for energy savings, which was then converted to dollars based upon the estimated value of energy during the years in which the energy savings were anticipated. Such an approach was not possible in this project because value to the warfighter is not easily measured using dollars or other conventional economic metrics. Instead, we adopted a scenario-based approach, basing the value of capabilities sought through R&D on their potential impact on accomplishing missions in specific warfighting scenarios. As a concrete example, we used an island defense scenario that was developed and used recently to define measures of effectiveness to the military of new technologies (Perry et al., 2002). This scenario hypothesizes a small island nation (U.S. ally) facing a large hostile neighboring nation (enemy) determined to annex the island. It includes a defensive (cruise and ballistic missile attack) and an offensive (time-critical target of opportunity) component to be considered separately. The situation is provided as context for coordinated operations involving individual units working together to achieve the defensive and offensive objectives. The effect of network-centric and/or “traditional” coordination and information sharing between units is critical to the outcome of the scenario. CDR Geoffrey Stothard, USNR, prepared a detailed description of this scenario, and specifically identified high-level and enabling capabilities required to successfully achieve mission objectives. This scenario description is presented in Appendix B.

We defined² the value of capabilities sought through R&D based on their importance to the island defense scenario, and also on the extent to which they were deemed useful in other important scenarios. This dual approach recognized the value of capa-

² This paragraph and the following paragraphs describe the *definitions* of the Expected Value components in the PortMan decision framework. The actual evaluation of these components requires values assigned according to the anchored scales. This was done in the case study by the expert panel, as described in Chapter 4.

bilities with pervasive applicability to important warfighting scenarios, but that might not have played as prominent a role in the island defense scenario.

Performance Potential

Each capability required by the island defense scenario, or any other scenario, has a minimum specified level of performance needed to accomplish the mission. We defined the performance potential of each R&D project in terms of the quality of the match between the technical performance that would be achieved if the R&D were successful and this level of needed operational performance. Further, to achieve a high value of performance potential, the level of needed performance must be accomplished under conditions that are relevant to the scenario for which the capability is required. For example, consider a new communications technology that increases speed and bandwidth of voice and data transmission. Its performance potential will depend on the extent to which these increases actually enable the success of coordinated operations in the island defense scenario or other important scenarios. This will require not only improved technology, but also improved operation within the constraints of the scenario (e.g., atmospheric interference, specific sea states, lack of technical support).

Transition Probability

Transition probability is the probability that the capability will both be achieved at its potential level of performance, and transitioned to higher levels of R&D and eventual use by the fleet. This takes into account both the technical problems that must be solved to successfully achieve the research objectives, and the difficulties associated with bridging the gap between 6.3 and 6.4, as well as any special burdens associated with fielding the capability. We evaluated transition probability in terms of the severity of the remaining technical problems to accomplish the research objectives, the quality of the transition plan, and the experience of the project team with developing and fielding similar technologies.

Value Descriptions and Scales

In the prior application of this decision framework to industrial materials research, RAND used anchored scales that specified the threshold requirements for assigning specific values. For example, on a scale from 0 to 1, the requirement for assigning a 1 for performance potential was that: “Experimental data and technical literature indicate that the desired materials properties *have been achieved* by the candidate material under *all necessary conditions*.³ Thresholds for other values on the scale were defined according to combinations of the level of achievement of the suite of materials properties and the conditions under which they were achieved. For example, 0.75 corresponded to *partial achievement under most conditions*.

³ Silbergliitt and Sherry, 2002, Table 3.2, p. 26.

In the current effort, RAND both clarified and simplified the use of the anchored scales by: (1) separating the factors that entered into the scale value descriptions (level of achievement and conditions in the above example), (2) asking explicit questions to determine each one, and (3) defining scales based on all possible combinations of the answers. This allowed the evaluators to focus separately on each aspect of value and to consider each aspect of the R&D project independently. For capability, the aspects considered were importance to the island defense scenario and pervasiveness of impact across important scenarios. For performance potential, the aspects were achievement of specified level of performance and extent to which these were achieved under relevant scenario conditions. For transition probability, the aspects were extent of remaining technical problems, experience fielding similar technology, and quality of the transition plan. The actual value descriptions and scales used in the case study are shown in Tables 3.1 through 3.6 and Appendix C.

Table 3.1
Capability

The capability that the project is aimed at achieving will be evaluated based on its importance, at a specified level of performance, to a specific warfighting scenario, as well as the extent to which it influences other important scenarios.

Assuming the project is fully successful, the resulting capability would be:

- Critical to success in the scenario
- A major factor for success in the scenario
- Helpful to success in the scenario
- Not relevant to or possibly detrimental to success in the scenario

How would you assess the applicability of this resulting capability across important scenarios?

- Pervasive across many scenarios
- Useful in a number of different scenarios
- Applicable to a very limited number of scenarios similar to this one

Table 3.2
Performance Potential

The performance potential will be evaluated based on the extent to which the project may provide performance consistent with achieving the required capability.

Assuming the project is fully successful, the performance needed to achieve the required capability for the scenario would be:

- Fully achieved
- Partially achieved
- Hardly achieved at all

Assuming that the project is fully successful, the performance described above would be achieved under:

- All relevant scenario conditions
 - Most relevant scenario conditions
 - Some relevant scenario conditions
 - A limited number or none of the relevant scenario conditions
-

Table 3.3
Transition Probability

The transition probability will be evaluated based on the quality of the transition plan and the difficulty of remaining technical and fielding problems.

The project and project team is presently characterized as:

- No remaining technical problems; experience fielding similar technology
- Remaining technical problems; experience fielding similar technology
- No remaining technical problems; no experience fielding similar technology
- Remaining technical problems; no experience fielding similar technology

The transition plan for this project is:

- Well conceived and appears to be implementable
 - Has some problems with cost, schedule, or other fielding burdens
 - Has major problems with cost, schedule, or other fielding burdens
 - Is severely flawed or nonexistent
-

Table 3.4
Capability Scale

	Pervasive	Number of Different	Limited Number
Critical	5	4	3
Major Factor	4.5	3.5	2.5
Helpful	4	3	2
Not Relevant	3	2.5	1

Table 3.5
Performance Potential Scale

	Fully	Partially	Hardly At All
All	5	4	2.5
Most	4	3	2
Some	3	2.5	1
Limited or None	2	1	0

Table 3.6
Transition Probability Scale

	No Technical Problems	No Experience Fielding	Technical Problems and No Experience
	No Technical Problems and Experience Fielding	or Technical Problems Experience Fielding	Fielding
Implementable	5	4	3
Some Problems	4	3	2
Major Problems	3	2	1
Severely Flawed	2	1	0

Data Requirements

Effective use of the anchored scales requires accurate and sufficient data. In this effort, RAND used the scenario definition shown in Appendix B, together with the combined expertise of an expert panel of senior naval officers and civilian executives for the capability evaluation. For performance potential and transition probability, the RAND project staff compiled summaries of each of the 20 ONR Code 31 6.2 research projects evaluated in the case study. These summaries were based on proposal information provided by ONR, and were compiled in a consistent format for each project that included an overview, and all specific information relevant to each of the questions in Appendix C, each in a separate section with appropriate title. The project summary format is shown in Table 3.7 and Appendix D.

In some cases, there was insufficient data in proposals to compile necessary sections of the summary. In these cases, RAND staff contacted the Principal Investigators

Table 3.7
Project Summary Format

Project Title
Overview
A brief summary of the project background and objectives, including:
<ul style="list-style-type: none"> – The goal for the operational capability of the project – Who is going to use it or benefit from it – What is being proposed
Capability
Description of the operational capability that is being sought through R&D, who is going to use it, and why it is needed.
Performance Potential
Description of the level of performance that is being sought through R&D, and the conditions under which the performance will be achieved. For example:
<ul style="list-style-type: none"> – Savings in some combination of time (e.g., time-to-attack), quality (e.g., of data), and cost (e.g., operational cost, acquisition cost, maintenance cost) – Improvement over performance of an existing system by specific amount
Transition Probability
<i>Technical Approach:</i> Description of the technical approach to achieving the objectives, including discussion of the current state-of-the-art and how it will be improved by the R&D and the current status of the research.
<i>Experience Fielding:</i> Description of any experience of members of the project team with fielding similar capabilities or technologies.
<i>Transition Plan:</i> Description of the intended transition targets and the plan for accomplishing transition of the capability to development and fielding, including current status.

of the projects to request additional information, which was included in the summary.

We note that the case study evaluation, like any evaluation using anchored scales, was limited by the available data. As noted in Chapter 4, some members of the expert panel commented that they thought the island defense scenario was too limited in its

scope of required capabilities. As stated above, RAND used a second aspect, pervasiveness across important scenarios, in the anchored scale for capability in an effort to counteract such a problem. However, in future uses of the decision framework by ONR, we recommend that specific scenarios (e.g., Office of the Secretary of Defense (OSD)/Joint Chiefs of Staff (JCS)-approved scenarios) or other means of defining warfighting requirements be defined by the Navy, in order to ensure that capability valuation is in accordance with current priorities.

Members of the expert panel also commented that they needed more information on the R&D projects than was available in the project summaries in order to accurately answer the anchored scale questions. In future uses of this decision framework by ONR, we recommend that the Program Managers or the Principal Investigators of the projects compile the summaries, based on specific data requirements. To ensure that sufficient data are available for the evaluation, ONR could provide the summaries in draft form to the evaluators prior to Round 1 of the evaluation, allow them to ask for additional data where desired, and then have revised summaries meeting these requirements prepared before Round 1. This approach requires a commitment of time and effort by ONR and the research performers, but would ensure that the evaluation is based on the best available data on the R&D projects.⁴

It is important to keep in mind that the evaluation described in this report is only a case study application of the RAND PortMan R&D portfolio management decision framework. As such, it was performed within the time and budget constraints of the project and should not be regarded as a complete or accurate evaluation of the 20 sample R&D projects evaluated. It is, however, valid as a case study demonstration of the use of the framework, because all of the evaluators had exactly the same data on which to base their evaluations, and the RAND E-DEL+I consensus generation method was consistently applied using the decision framework's anchored scales, together with a representative and well-qualified expert panel.

Overview of the RAND E-DEL+I Technique and Process

E-DEL+I is a collaborative consensus-building method that combines hardware, software, networking, and communications capabilities with interlinking mathematical processes to effectively create collaborative working environments in which experts in diverse locations can virtually work side by side to accomplish phases of research. E-DEL+I exercises can be conducted in two modes: real-time and non-real-time modes. In the real-time mode used in this work, a multi-round consensus-building

⁴ Among the lessons learned in the DoN Fiscal Year 2000 6.3 Review (Kostoff et al., 2001) was that a successful R&D evaluation requires a high-level commitment of the organization to, among other things, allocate the time and effort necessary to prepare adequate data.

exercise can be completed in as little as two hours with only basic business tools such as a telephone, email, and a standard software package such as Excel.

Comparison of E-DEL+I and Traditional Consensus Building Methods

E-DEL+I retains the positive aspects of traditional consensus-building methods, while avoiding the principal drawbacks associated with the traditional techniques. One traditional primary method is to conduct live discussions among expert panel members. This method favors participants with the strongest oral communication skills. In addition, implementations of the discussion method generally involve bringing together experts to a single location, a task that requires considerable logistical coordination and can be expensive.

The other primary method involves written exercises. For example, the traditional Delphi method (Dalkey, 1969) is a technique for conducting consensus building exercises in writing. The hallmarks of the traditional Delphi method are that the participants are anonymous, and that the assessments are made independently.⁵ Its drawbacks are that it favors participants with strong writing skills, it does not permit the benefits of live discussions among the experts to be captured, and it can be very time consuming. Such an approach can be costly to implement, and follow up is invariably required to maximize participation.

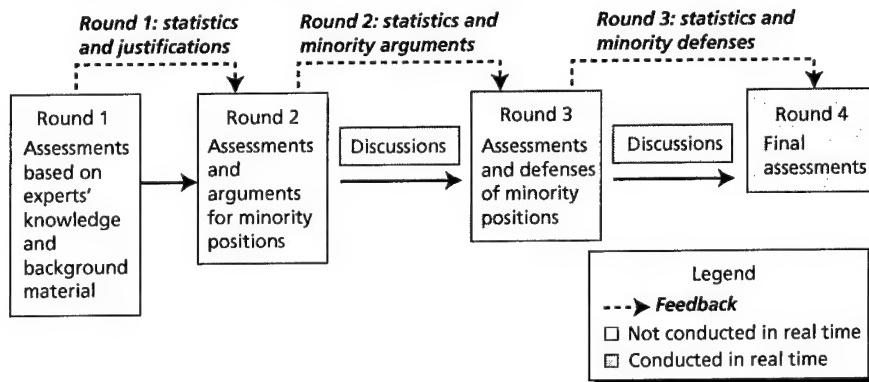
E-DEL+I allows for written arguments and responses, as well as live discussions among exercise participants, while preserving anonymity and independence. In addition, E-DEL+I allows participants to be physically located in diverse locations during the exercise. A typical real-time portion of an E-DEL+I exercise can be completed in the time span of a business meeting (two to three hours). Complete four round exercises using E-DEL+I can be accomplished in as little as a day, extended to a few weeks, or designed for any desired time span. Hence completing an E-DEL+I exercise can take only a fraction of the time that traditional methods require. In addition, since the exercises exploit commonly existing electronic capabilities and infrastructure, with no traveling expenses, E-DEL+I exercises are typically far less expensive to complete than comparable traditional exercises.

The E-DEL+I Process

The E-DEL+I process, consisting of four rounds, is schematically represented in Figure 3.2. In the first round, experts supply assessments in response to a questionnaire that presents the research questions. For the case study application of the RAND Port-

⁵ A number of organizations have successfully used Delphi techniques for planning in the face of uncertainty. The Graduate School of Business at the University of Southern California (USC) regularly conducts Delphi-like exercises that involve several dozen experts. Japan and Germany use Delphi approaches to determine consensus of their national experts on future trends in science and technology for the purpose of strategically orienting Japanese and German economies towards future markets (NISTEP, 1994). The French Bureau d'Economie Theorique et Appliquee and the Laboratoire d'Intelligence Organisationnelle used a Delphi-like study to derive explanatory trajectories to fight diseases such as cancer and Alzheimer's disease (Ronde, 2001).

Figure 3.2
E-DEL+I Consensus Formation Process



RAND MG271-3.2

Man decision framework, the research questions were the anchored scale questions presented in Tables 3.1 to 3.3 and Appendix C. The first round assessments are based on the individual specialized knowledge of each expert, using the data provided in the background material, which in this case was the scenario shown in Appendix B, together with the project summaries compiled by RAND, in the format shown in Table 3.7 and Appendix D.

The input for the second round is a statistical summary of the first-round inputs, along with written justifications of the round one assessments that were provided by the experts. This is forwarded to each participant, along with a blank (second round) questionnaire. The experts review the feedback material and make a second assessment, this time supplying arguments for any first-round minority positions.

In the case study, the first two rounds were conducted electronically, but not in real time. The questionnaire and background materials were sent to the experts, and their responses received, using email, over a period of about one week. This allowed the participants the opportunity to review the background material and familiarize themselves with the questionnaire format.

Rounds 3 and 4 were conducted in real time, and were preceded by a facilitated telephone conference discussion that was focused on areas in which consensus had not been reached in the first two rounds. The facilitator's role was to direct the discussions and to ensure that all viewpoints were heard. Following this discussion period, the E-DEL+I process calls for a statistical summary and minority arguments from the second round to be provided to the experts, along with a blank questionnaire for the third round. In the third round, participants again provide assessments and defenses for minority positions, this time after reviewing the feedback material and considering what was presented during the discussion period. A second real-time discussion period then focuses on remaining unresolved issues. The summary and minority opinions, along with a fourth questionnaire are sent to the participants at the end of this second

discussion period. In the fourth round, the experts provide their final assessments, after reviewing and considering all of the feedback material, as well as insights they may have gained from the discussion periods. The final consensus positions are derived from statistical analysis of this final assessment, which, like each of the previous ones, the experts complete independently.

Previous RAND Experience Using the E-DEL+I Method

RAND has used E-DEL+I to complete a phase of research for four Army projects. In each case, the research question involved experts in a number of Army areas. Two of the exercises were real time, another was not real time, and the fourth was a hybrid.

Army Basic Research Technologies This real-time E-DEL+I exercise sought to determine optimal outsourcing approaches for Army Basic Research (6.1) areas. Fourteen participants assessed twelve Basic Research areas with respect to five outsourcing approaches. At the end of the fourth round, consensus was reached on eleven of the twelve areas (92percent) (Wong, 2003).

Army Applied Research Technologies This real-time E-DEL+I exercise sought to determine optimal outsourcing approaches for Army Applied Research (6.2) technologies. Fourteen participants assessed twenty Applied Research technologies with respect to five outsourcing approaches. At the conclusion of the fourth round, a consensus was reached on eighteen of the twenty technologies (90percent) (Wong, 2003).

Assessment of Organizational Structure Alternatives for Army Research This non-real-time exercise sought to assess fifteen organizational structure alternatives on how well the structures are suited for accomplishing eight critical Army research functions. Many of the organizational structure alternatives were innovative concepts not yet in practice. We judged this effort, with 120 responses requested per round, to be too large for a real-time exercise. At the end of the fourth round, consensus was reached on 93percent of the 120 points.

Alternative Armies This project used an E-DEL+I exercise to refine approaches to Army strategic direction. Twenty-four experts assessed six alternative strategic directions against sixteen criteria. A hybrid approach was used for this exercise whereby the participants participated in three real-time discussions and a mandatory preparatory

session, but completed the questionnaires over a series of four two-day periods. By the end of the fourth round, the experts reached consensus on 96 percent of the points.

We will see in Chapter 4 that the case study of the RAND PortMan decision framework involved five to seven experts who assessed twenty Navy Applied Research (6.2) projects with respect to six dimensions. At the end of the fourth round, consensus was reached on 91 percent of the issues.

Case Study Description

This chapter describes the case study evaluation of 20 sample ONR Code 31 6.2 applied research projects that RAND performed using its E-DEL+I method to apply its PortMan decision framework. This case study was performed between January 19 and January 30, 2004.

Composition of the Expert Panel

The case study evaluation was performed by an expert panel of senior Naval officers and civilian executives. The panel was drawn from a list of candidates compiled by senior RAND and ONR staff, with assistance from USNR officers. The criteria for panelists was breadth and depth of experience that would provide expertise to answer the questions in Tables 3.1 to 3.3 and Appendix C for specific ONR applied research projects, as well as the absence of conflicts of interest with respect to these projects. RAND also sought a balance of organizational and technological perspectives in order to avoid overall bias. Twelve individuals initially agreed to serve on this panel, but a number of these found that they were unable to meet the required commitment. Seven panel members completed the first round evaluation, and five of these completed all four rounds. The composition of the panel (organization represented and location) is shown in Table 4.1.

The Sample ONR Code 31 6.2 Research Projects

The projects to be evaluated were chosen from a group of proposals provided to RAND by ONR Code 31 management. All were 6.2 proposals in either the Command, Control and Combat Systems (C2CS) or Communications subunits of Code 31 and were categorized within the early stage D&I part of 6.2. Projects were combined if they were strongly related, and the primary selection criterion was the amount of data available

Table 4.1
Representation of Navy E-DEL+I Panel of Experts

Representation	Location
Naval Postgraduate School	Monterey, California
Operational Liaison Defense Advanced Research Projects Agency (DARPA)	Arlington, Virginia
NETWARCOM	Norfolk, Virginia
Naval War College	Newport, Rhode Island
Navy Systems Interoperability Center	San Diego, California
Plans and Programs Office of Defense Research and Engineering (OSD-ATL)	Washington, D.C.
Expeditionary Warfare Division (N75) in OPNAV	Washington, D.C.

in the proposals. We note that these projects are a small fraction of Code 31 and are not necessarily representative as a group of either Code 31 or its D&I component. In some cases, RAND staff called the Principal Investigators in order to request additional data that would make the project suitable for the evaluation. Appendix E gives a brief overview of each project, using generic project titles. The actual project titles and the project summaries in the format of Table 3.7 and Appendix D are not provided in this report for reasons of confidentiality, but are available with proper authorization through request of the sponsor. Table 4.2 shows the generic project titles and abbreviations for the projects used in the analysis described in Chapter 5.

The Assessment Dimensions

The expert panel members individually assessed each project with respect to six dimensions. These dimensions were the questions shown in the value descriptions of the RAND PortMan decision framework, as adapted for ONR (Tables 3.1 to 3.3 and Appendix C). The dimensions for capability were relevance (to the island defense scenario show in Appendix B) and applicability (across a range of important warfighting scenarios). The dimensions for performance potential were achievement (of required performance level) and conditions (relevant to warfighting scenarios). The dimensions for transition probability were status (judged in terms of remaining technical problems and experience of the project team with fielding similar technologies) and implementability (judged in terms of quality of the transition plan). The experts evaluated each project by selecting from the list of responses shown in Tables 3.1 to 3.3 and Appendix C the one that they believed best completed the statement for that dimension and that project. Their responses were based on their expertise and the data provided, which consisted of the scenario description (Appendix B) and the project summaries (in the format shown in Table 3.7 and Appendix D). They were also asked to provide comments that explained their choices of responses.

Table 4.2
Case Study Project Titles and Abbreviations

Generic Project Titles	Abbreviations
Alternative Human-Machine Interface Project 1	A1
Alternative Human-Machine Interface Project 2	A2
Alternative Human-Machine Interface Project 3	A3
Distributed Sensor Fleet Project 1	D1
Distributed Sensor Fleet Project 2	D2
Expeditionary Comms Infrastructure Project 1	EI1
Expeditionary Comms Infrastructure Project 2	EI2
Expeditionary Comms Infrastructure Project 3	EI3
Expeditionary Comms Infrastructure Project 4	EI4
Expeditionary Comms Upgrade Project 1	EU1
Expeditionary Comms Upgrade Project 2	EU2
Network/Information Infrastructure Project 1	N1
Network/Information Infrastructure Project 2	N2
Optimization or Decision-Aid Project 1	O1
Optimization or Decision-Aid Project 2	O2
Optimization or Decision-Aid Project 3	O3
Optimization or Decision-Aid Project 4	O4
Optimization or Decision-Aid Project 5	O5
Optimization or Decision-Aid Project 6	O6
UAV General Research Project 1	U1

The Assessment Questionnaire

The assessment questionnaire was an Excel workbook consisting of 11 worksheets, as described in the following. Six of the worksheets included assessment forms for one of the six assessment dimensions. The other worksheets provided information, instructions, summaries of the assessments completed so far, and, after the initial round, statistical feedback on the responses of other experts.

General Info

This worksheet listed the events that would occur during the exercise. It described the material each expert would receive for each round, the actions they were expected to take in each round, and the due dates of each round's response.

Relevance

This worksheet contained the definition of the Capability/Relevance dimension and the assessment form the experts would complete to record their assessments of the 20 projects with respect to Capability/Relevance.

Applicability

This worksheet contained the definition of the Capability/Applicability dimension and the assessment form the experts would complete to record their assessments of the 20 projects with respect to Capability/Applicability.

Achievement

This worksheet contained the definition of the Performance Potential/Achievement dimension and the assessment form the experts would complete to record their assessments of the 20 projects with respect to Performance Potential/Achievement.

Conditions

This worksheet contained the definition of the Performance Potential/Conditions dimension and the assessment form the experts would complete to record their assessments of the 20 projects with respect to Performance Potential/Conditions.

Status

This worksheet contained the definition of the Transition Probability/Status dimension and the assessment form the experts would complete to record their assessments of the 20 projects with respect to Transition Probability/Status.

Implementability

This worksheet contained the definition of the Transition Probability/Implementability dimension and the assessment form the experts would complete to record their assessments of the 20 projects with respect to Transition Probability/Implementability.

Summary

This worksheet automatically recorded the expert's assessments. The experts could use this worksheet to see an overview of their assessments and to identify which assessments they had not yet made. It included the instruction: "No entries should be made on this worksheet."

Reference

This worksheet included the project summaries compiled by RAND in the format of Table 3.7 and Appendix D, one for each of the 20 ONR Code 31 6.2 projects, as well as the description of the island defense scenario (Appendix B). It also included a directory with links that facilitated navigation within this worksheet to review specific projects.

Feedback

This worksheet provided a summary overview of the statistical modes for the previous round's responses. This worksheet was not included in the Round 1 packages.

Rd X Text

This worksheet contained the (anonymous) supporting arguments and written general comments submitted with the previous round's responses. This worksheet was not included in the Round 1 packages.

In order to make the workbook more user-friendly, each of the six assessment worksheets contained directions, links to the project summaries and the scenario, drop-down menus with the assessment response choices, the statistical feedback of the previous round for that dimension, and a link to the supporting arguments of the previous round. An example of the Round 2 Capability/Relevance worksheet is shown in Figure 4.1.

Dynamics of the Evaluation

There were seven participants in Round 1 of the exercise, which was accomplished via email from January 19–21, 2004. Using a simple majority consensus standard, under which consensus is declared if more than half of the participants (i.e., 4 out of 7 for this panel) support a particular position, 59 of 120 (6 × 20) project–dimension pairs (49 percent) reached consensus. This is higher than comparable to past exercises, in which approximately 30 percent show a consensus position in the first round.

Figure 4.1
Screenshot from E-DEL+I Excel Workbook

Click here for Round 3 Supporting Arguments			
Project Name	Click here for Scenario	Assessment	Explanation of Assessment
Alternative Human-Machine Interface Project 1		<input checked="" type="checkbox"/> Critical	Critical = Critical to success in the scenario.
Alternative Human-Machine Interface Project 2		<input checked="" type="checkbox"/> Major factor	Major factor = A major factor for success in the scenario.
Alternative Human-Machine Interface Project 3		<input checked="" type="checkbox"/> Helpful	Helpful = Helpful to success in the scenario.
Distributed Sensor Fleet Project 1		<input checked="" type="checkbox"/> Not relevant	Not relevant = Not relevant to or possibly detrimental to success in the scenario.
Distributed Sensor Fleet Project 2			
Expeditionary Comms Infrastructure Project 1			
Expeditionary Comms Infrastructure Project 2			
Expeditionary Comms Infrastructure Project 3			
Expeditionary Comms Infrastructure Project 4			
Expeditionary Comms Upgrade Project 1			
Expeditionary Comms Upgrade Project 2			
Network/Information Infrastructure Project 1			
Network/Information Infrastructure Project 2			
Optimization or Decision-Aid Project 1			
Optimization or Decision-Aid Project 2			
Optimization or Decision-Aid Project 3			
Optimization or Decision-Aid Project 4			
Optimization or Decision-Aid Project 5			
Optimization or Decision-Aid Project 6			
UAV General Research Project 1			

Please click on the arrow and select an assessment.

Dominant Response (Mode)	Frequency Distribution		
	Critical factor	Major factor	Helpful
Not-relevant	0	1	3
Helpful	0	2	3
Major factor	0	0	5
Critical	0	2	3
Helpful	0	1	4
Not-relevant	1	0	2
Helpful	1	0	4
Helpful	0	1	4
Major factor	0	4	1
Helpful	0	1	4
Major factor	0	3	2
Helpful	0	3	2
Helpful	0	1	4
Helpful	0	0	4
Helpful	0	0	5
Not-relevant	0	0	3
Helpful	0	0	4
Helpful	0	0	5
Helpful	0	1	4
Helpful	0	0	4

All seven participants completed Round 2, which was accomplished via email from January 23–26, 2004. Using the same simple majority consensus standard, 104 of 120 project–dimension pairs (87 percent) reached consensus. This dramatic rise is typical of Round 2 results, although the magnitude of consensus is significantly higher than comparable to past exercises, in which approximately 50 percent show a consensus position in the second round. We believe that the dramatic rise in Round 2 consensus is due to “normalization” of interpretations that the experts gain by reviewing the statistical feedback and reading the justifications of their colleagues. Some of the increase may also be attributed to changed assessments motivated by the written feedback material.

After the second round, ten projects showed consensus in all six dimensions. Of the remaining ten projects, the least understood dimension was Performance Potential/Conditions. RAND prioritized the issues to be discussed during the teleconference held on January 30, 2004 based on the number of nonconsensus dimensions remaining for each project. During the first discussion period, which was held at the beginning of the teleconference, and in which five of the experts participated, discussions were held on the six projects that had more than one nonconsensus dimension.

Round 3 was completed by the five participants during a break in the teleconference after the first discussion period. Using the same simple majority consensus standard (three out of five for Round 3), 111 of 120 project–dimension pairs (93 percent) reached consensus. This increase is less than typical Round 3 results, in which improvements average 20 to 30 percentage points. However, the Round 2 results were exceptionally high, so in absolute terms, the Round 3 consensus percentage was within the typical Round 3 range. More significantly, Round 3 showed a consensus for eight of the eleven project–dimension pairs that were discussed during the first discussion session. This indicates that the discussions were of value and that the exchange helped the experts come to agreement on 73 percent of the points discussed. The discussions also resulted in other changes of position, hence only seven more project–dimension pairs reached majority consensus in Round 3 as compared to Round 2. We note, also, that since the number of participants dropped from seven in Round 2 to five in Round 3, the Round 3 results used a different majority standard to determine consensus. After the third round, a total of eleven projects showed consensus in all six dimensions. Of the remaining nine projects, the least understood dimension was still Performance Potential/Conditions.

Expert Panel Concerns and Final Assessments

After the participants completed and submitted their Round 3 responses, the teleconference resumed with a second discussion session. During this session, individual expert panel members were allowed to raise general issues concerning the exercise. The two issues that most concerned the panel were the choice of scenario and the absence of cost and schedule information in the project summaries.

Concerns with respect to the scenario were that it was too limited in terms of both missions and applicable capabilities. As noted previously, the dimension Capability/Applicability was intended to counterbalance this potential problem by basing the evaluation on all scenarios that the expert believed important. Nevertheless, the RAND project team concluded that in future applications of this framework, the decision on which scenario(s) to use to value capabilities should be made by the sponsor.

The second concern was that the experts found it to be exceedingly difficult to make a sound judgment on the Transition Probability/Implementability dimension without cost and schedule information on the projects. Since this information was absent because it had not been available in a uniform enough fashion in the proposals, one way to solve this problem would be to require the Principal Investigators to provide these data for the evaluation.

Overall, members of the expert panel expressed satisfaction with the format of the exercise and found it to have been useful and insightful. Most stated that they learned something from their participation.

All five participants completed Round 4 following the teleconference, and submitted their final assessments to RAND via email within a few days. Using the same simple majority consensus standard, 109 of 120 project-dimension pairs (91 percent) reached consensus. This small drop in consensus is not typical, but has been seen in other exercises. It shows that two Round 3 consensus positions were quite weak. For the fourth and final round, the experts were to give final assessments considering all of the feedback material and exchanges made during the discussions, as if each of them were the final decisionmaker. Under these conditions, some experts changed their positions, indicating that they were not thoroughly convinced of the Round 3 assessments. Still, in absolute terms, the Round 4 consensus percentage was within the typical Round 4 range.

A total of eleven projects showed consensus in all six dimensions. Of the remaining nine projects, the least understood dimension was again Performance Potential/Conditions. Eight project-dimension pairs showed double modes (i.e., two different positions tied with the most participants choosing them) in the final assessments. This is higher than typical, but not surprising because of the relatively small number of participants. Only three of the double modes indicate bipolar splits. The other double modes were in adjacent positions, so small differences of interpretation can account for these results. Figure 4.2 shows an example of the modes (assessment positions with the highest frequency of responses) of the frequency distributions of the Rounds 1–4 responses for Capability/Relevance. The shaded cells show where majority consensus positions were achieved.

Summary of Consensus Positions

This case study evaluation exhibited several consensus-building patterns, ranging from a consensus in the first round that held through the last round, to double modes and

Figure 4.2
Modes and Consensus Positions for Capability/Relevance

Project Designator	Project	Relevance Modes			
		Round 1	Round 2	Round 3	Round 4
A1	Alternative Human-Machine Interface Project 1	Helpful	Helpful	Helpful	Helpful
A2	Alternative Human-Machine Interface Project 2	Helpful	Helpful	Helpful	Helpful
A3	Alternative Human-Machine Interface Project 3	Helpful	Helpful	Helpful	Helpful
D1	Distributed Sensor Fleet Project 1	Helpful	Helpful	Helpful	Helpful
D2	Distributed Sensor Fleet Project 2	Helpful Not relevant	Helpful Not relevant	Helpful Not relevant	Helpful Critical
EI1	Expeditionary Comms Infrastructure Project 1				Helpful
EI2	Expeditionary Comms Infrastructure Project 2	Not relevant	Not relevant	Helpful	Helpful
EI3	Expeditionary Comms Infrastructure Project 3	Helpful Major factor	Helpful Major factor	Helpful Major factor	Helpful Major factor
EI4	Expeditionary Comms Infrastructure Project 4	Helpful			
EU1	Expeditionary Comms Upgrade Project 1	Helpful	Helpful	Major factor	Major factor
EU2	Expeditionary Comms Upgrade Project 2				Helpful
N1	Network/Information Infrastructure Project 1	Helpful	Helpful	Helpful	Major factor
N2	Network/Information Infrastructure Project 2	Helpful	Helpful	Helpful	Helpful
O1	Optimization or Decision-Aid Project 1	Helpful	Helpful	Helpful	Helpful
O2	Optimization or Decision-Aid Project 2	Helpful	Helpful	Helpful	Helpful
O3	Optimization or Decision-Aid Project 3	Not relevant Helpful	Not relevant Helpful	Not relevant Helpful	Helpful Helpful
O4	Optimization or Decision-Aid Project 4	Not relevant			
O5	Optimization or Decision-Aid Project 5	Helpful	Helpful	Helpful	Helpful
O6	Optimization or Decision-Aid Project 6	Helpful	Helpful	Helpful	Helpful
U1	UAV General Research Project 1	Helpful Not relevant	Helpful	Helpful	Helpful

RAND MG271-4.2

no consensus throughout the four rounds. Although there was the unusual occurrence of a drop in the number of participants in Round 3, the overall pattern towards consensus was not disturbed. Table 4.3 shows a round-by-round summary of the consensus positions of the expert panelists for each of the six assessment dimensions. The entries for each assessment dimension are the number of projects for which there was a simple majority consensus for that round, with a possible maximum of 20. The total is the sum of the consensus positions for each project, with a possible maximum of 120. The percentage is the percentage of project/assessment pairs for which consensus was achieved. After Round 4, five of the six assessment dimensions showed a majority consensus in at least 18 of the 20 projects, with the dimensions Capability/Applicability and Transition Probability/Status showing consensus for all 20 projects. This suggests that, despite the problems with data and scenarios discussed above, the experts were able to agree on most of the assessment dimensions.

The one dimension in which there was substantial lack of consensus was Performance Potential/Conditions, for which only 14 of 20 projects showed consensus. We note that on the other Performance Potential dimension—Achievement, consensus was reached for 19 of the 20 projects. So the experts did agree on the ability to achieve the required performance levels, but not on whether or not they could be achieved under conditions relevant to the island defense scenario and other important scenarios. This may reflect the difficulty of specifying the exact conditions of use and, especially, the need for detailed performance-level research objectives under specific conditions

Table 4.3
Summary of Consensus Positions of the Expert Panelists

	Number of Occurrences of Majority Consensus							Percentage
	Relevance	Applicability	Achievement	Conditions	Status	Implementability	Total	
Round 1	10	12	10	7	8	12	59	49%
Round 2	19	20	17	12	18	18	104	87%
Round 3	19	20	19	15	20	18	111	93%
Round 4	18	20	19	14	20	18	109	91%

in order to properly evaluate applied research proposals. In future uses of this decision framework, such detailed data will be sought, together with more detailed descriptions of required capabilities and operational conditions for the scenario(s) used in the evaluation.

As we shall see in Chapter 5, the level of consensus reached for the 120 project-dimension pairs was sufficient to determine the three components of EV and then perform a portfolio analysis of the 20 projects, including explicitly the uncertainty in capability, performance potential, and transition probability defined by the spread of the expert assessments.

Analysis of the Case Study Results

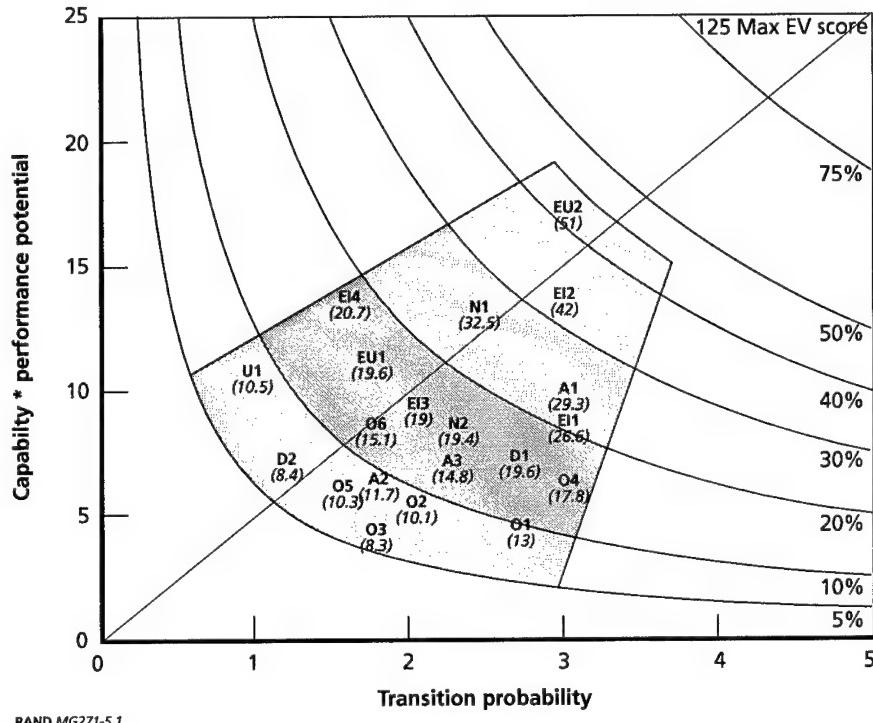
This chapter describes RAND's analysis of the case study results. We present the analysis in three parts. The first section shows the results for EV and compares the projects with respect to the ranges of EV into which they fall. The next section discusses the results for the three components of EV—capability, performance potential, and transition probability. This section also explains and provides some examples of our method for displaying uncertainty. The final section uses the case study results to demonstrate how to use the RAND PortMan decision framework to perform a portfolio analysis. We stress that, because of the limitations of this case study evaluation, principally insufficient data and a scenario of limited scope, these results should be viewed as an example and not an accurate representation of the projects that were evaluated.

EV Ranges of the Projects

The RAND E-DEL+I evaluation described in Chapter 4 provided five individual expert assessments on six dimensions for each of the 20 research projects. In this chapter, we combine the results for the appropriate pairs of dimensions that determine the three components of the EV of each project in the RAND PortMan decision framework (capability, performance potential, and transition probability), according to the scales shown in Tables 3.4 to 3.6 and Appendix C.

According to the RAND PortMan decision framework, the expected value (EV) of a research project is the product of capability, performance potential, and transition probability (Silbergliitt and Sherry, 2002). A useful interpretation of this equation is that the performance potential (i.e., the performance level that would be achieved if the project were successful), *scales* the capability value that is based on achieving a required level of performance. That scaled capability is then further reduced by the transition probability in order to obtain the *expected* value of the research, including its subsequent R&D stages and the fielding of the resulting process, component, or system. To visually capture these relationships, we plot in Figure 5.1 the *product* of the

Figure 5.1
EV Ranges of the Case Study Projects



mean values of capability and performance potential versus the mean values of transition probability.

The EV of each project is shown in Figure 5.1 in parentheses next to its data point. EV contours are also shown, expressed in percentages of the maximum EV of 125 (which corresponds to a value of 5 each for capability, performance potential, and transition probability). Figure 5.1 shows that the 20 projects fall into four distinct ranges of EV, indicated by the differently shaded bands. Projects EU2 and EI2 are in Band 1, with EV>30 percent of the maximum possible value. Projects H1, A1, and EI1 are in Band 2, with EV between 20 percent and 30 percent of maximum. Band 3, with EV between 10 percent and 20 percent of maximum, contains nine projects. Band 4, with EV<10 percent of maximum, contains six projects.

The straight line in Figure 5.1 from the origin to the maximum EV point at the upper right hand corner of the plot divides each band into two different regions. Projects in the same band but in different regions, except for those very close to this line, while they have similar EVs, are significantly different in character. For example, compare projects EI4 and O4. Their EVs differ by slightly more than ten percent, which is within our range of uncertainty (discussed below). However, project EI4 is ranked third on capability times performance potential, while project O4 is ranked fifteenth

out of twenty on this measure of value to the warfighter. O4 is in EV Band 3 because it is tied for first on transition probability, whereas EI4 is in EV Band 3 (as opposed to Bands 1 or 2) because it is third from last on transition probability. This suggests that O4 is seeking small improvement in existing capability, while EI4 has potential to make large advances or provide an important new capability.

By dividing the projects into EV Bands and regions of these bands, Figure 5.1 provides a straightforward indication of which projects were highly valued by the expert panel (i.e., Bands 1 and 2), and the risk-versus-reward characteristics of the projects. In particular, projects that are far from and above the line are potentially high-payoff projects that were judged not likely to transition. These require management attention to determine the reason for the low transition probability, and to determine if and how to increase the transition probability without affecting in a negative way the objectives and approach that resulted in their relatively high value to the warfighter.

By looking back at the evaluation data, the R&D manager, aided by the plot of Figure 5.1, can identify the projects with the greatest management leverage, and decide how to apply resources to improve transition probability while maintaining value, and push as many projects as possible into the upper regions of the upper bands. For the projects in the lower bands, the manager can determine from the data why these projects were relatively low in value, and decide whether or not the potential payoff can be improved (e.g., by increasing performance level objectives or changing technical approach).

The RAND PortMan decision framework provides a basis for a more detailed portfolio analysis that takes into account each of the components of the EV and their uncertainties. In the following sections, we discuss the components individually, then return to the EV plot and describe how to use it for portfolio analysis and investment strategy development.

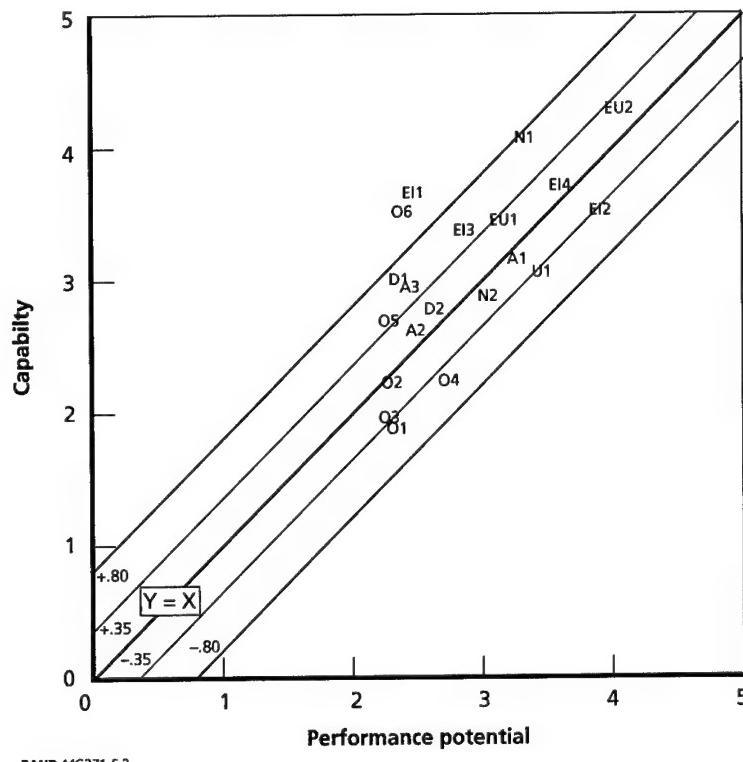
The Components of EV

The RAND E-DEL+I evaluation described in Chapter 4 provided five individual expert assessments on six dimensions for each of the 20 research projects. Here we use the mean of the five expert assessments, grouped in pairs according to the questions of Tables 3.1 to 3.3 and Appendix C, to compare the EV components. We then describe a method for explicitly displaying the uncertainty, or spread, around the mean value.

Capability versus Performance Potential

The mean values for capability, as determined from the mean values of its two assessment dimensions, Applicability and Relevance, are plotted in Figure 5.2 versus the mean values for performance potential, as determined from the mean values of its two assessment dimensions, Achievement and Conditions.

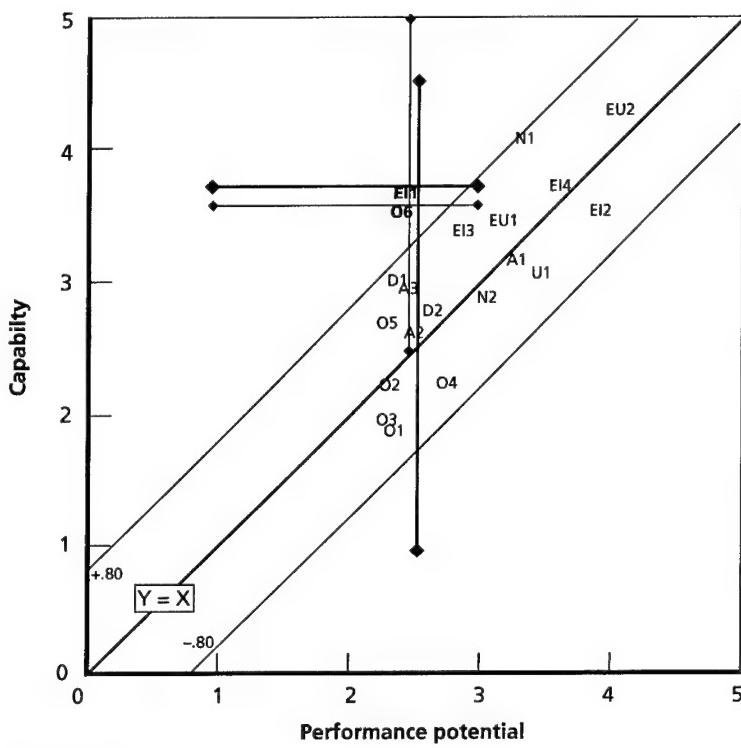
Figure 5.2
Capability versus Performance Potential



Most of the projects fall near the line $y = x$ on Figure 5.2, indicating that the differences between their capability and performance potential values are small. However, there are a few projects that fall significantly above the line, indicating that their capability objectives were highly valued by the expert panel, but their performance potentials were judged to be lower. In particular, the EI1 and O6 projects were the third and fourth highest valued projects for capability, yet were close to the lowest valued for performance potential. This suggests that these projects are aimed at an important capability, but that, in the view of the expert panel, their technical approach is not likely to deliver the level of performance required to achieve this capability. This result raises an important management question with respect to these projects (i.e., could an alternative technical approach have a better chance to achieve the required performance level?). The N1 project also falls into this higher capability than performance potential range, but it is still highly valued compared to its peers on both scales, so the management question here is whether or not an already strong project could be made even more valuable.

There are a few projects that fall below the line, in the higher performance potential than capability range, for which the technical approach was judged to be sound,

Figure 5.3
Capability versus Performance Potential with Uncertainty



RAND MG271-5.3

but the capability was ultimately judged to be less valuable (e.g., projects 04, U1, O1, O3). However, none of these are as far from the line as the three projects noted above. We will have more to say about some of these projects, as well as those in the group that is a similar distance above the line (e.g., projects D1, O5, and A3), in a later section of this chapter.

As noted previously, it is important to recognize that there is uncertainty in these estimates of the capability value, as well as in the estimates of required performance levels, and whether or not the proposed technical approach is capable of meeting them. The spread in the choices of the expert panel is an indication of this uncertainty. If the expert panel had been a larger group, we might represent their spread of choices as a standard deviation about the mean values plotted in Figure 5.2. However, with only five panelists, we instead chose to display the full range of values, as shown in Figure 5.3 for projects EI1 and O6 discussed above.

In Figure 5.3, the range of expert valuations is represented by two perpendicular straight lines that intersect at the mean value with that project's identifier. Note that the mean value is not at the center of both lines. This shows that the distribution of expert assessment values was not symmetric. If the mean value is very close to one end of either

uncertainty range, then a single expert was an outlier compared to a consensus or near consensus of the others. For project O6, every one of the experts rated capability significantly higher than performance potential. For project EI1, one expert was an outlier at equal values of capability and performance potential of 1, while the other four were in close agreement on both capability and performance potential similar to O6.

We note the relatively large uncertainty range. We believe that this resulted from two limitations of this case study: (1) the small number of experts; and (2) the data limitations, most notably the limited nature of the island defense scenario and the lack of data in the project summaries, especially with respect to cost and schedule. Neither of these limitations is inherent to this decision framework. Both were a result of resource limitations of the case study. In future uses of this framework, we will use a larger group of experts, as well as a better definition of capability value and more detailed data. This will both reduce the uncertainty range, and allow the use of standard deviation as a more useful measure of uncertainty. The current method of simply showing the extremes tends to emphasize the outliers.¹

Capability versus Transition Probability

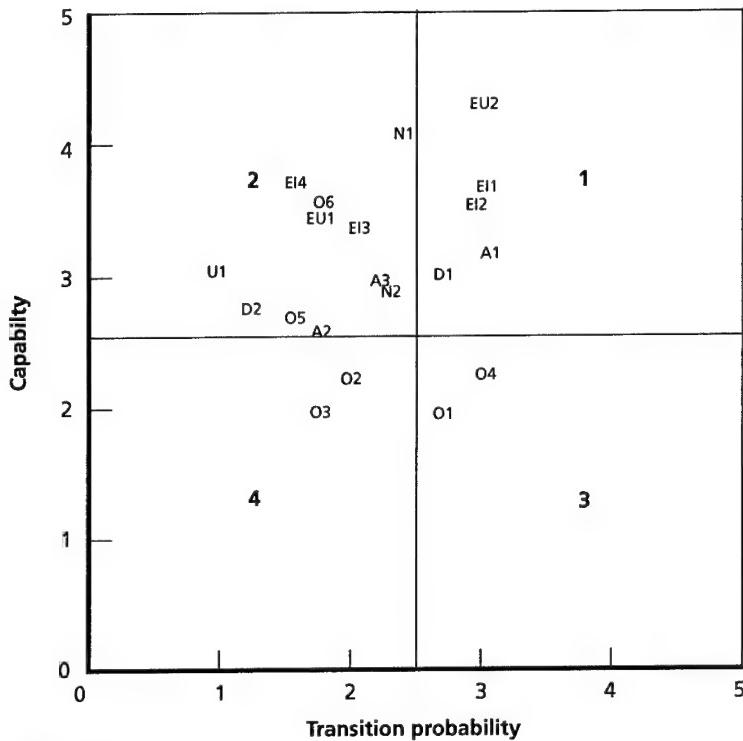
The mean values for capability, as determined from the mean values of its two assessment dimensions, Applicability and Relevance, are plotted in Figure 5.4 versus the mean values for transition probability, as determined from the mean values of its two assessment dimensions, Status and Implementability.

The plot of Figure 5.4 can be conveniently divided into quadrants, as indicated in the figure. Quadrant 1, which is populated by projects EU2, EI1, EI2, A1, and D1, with N1 near its border, is the region of high capability value and high transition probability. These are the projects that, if successful, will provide a highly valued capability, and also were judged by the experts to be most likely to be transitioned to use by the Navy. Quadrant 2, which is populated by projects EI4, O6, EU1, EI3, U1, O5, N2, D2, A3, and A2, is the region of high capability value and low transition probability. These projects, if successful, will also provide a highly valued capability, but, in the experts' judgments, have remaining problems of either a technical or fielding nature. Projects in this quadrant require careful attention, because some of them may simply be at a maturity level for which a transition plan is premature, or a transition plan has not yet been adequately developed, while others may have serious and even fundamental technical problems and fielding burdens.

Quadrant 3, which is populated by projects O4 and O1, is the region of low capability value and high transition probability. These are projects that are likely to be transitioned to provide incremental improvements in existing capabilities. Quadrant 4, which is populated by projects O2 and O3, is the region of low capability value and

¹ We note that it will also be possible to use standard deviation as a measure of uncertainty in the plot AND note the presence of significant outliers.

Figure 5.4
Capability versus Transition Probability



low transition probability. In the experts' judgment, these projects have serious problems with transition, and if transitioned, would provide little value.

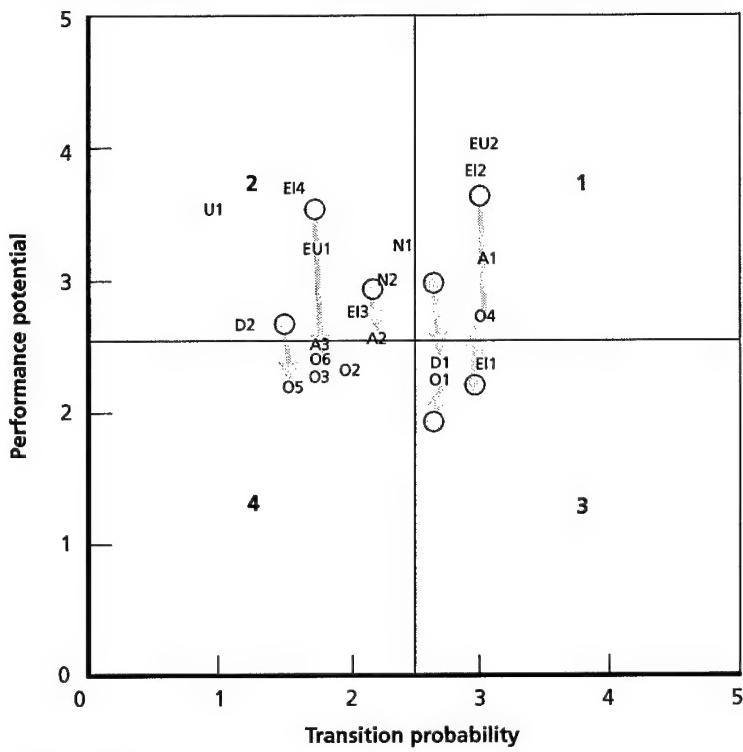
Figure 5.4 is useful as an indicator of which projects are aimed at valuable capabilities, and of how mature or well conceived their transition planning is. However, it does not show the quality of the technical approach (i.e., whether or not the projects are aimed at levels of performance required to achieve the capabilities). This is discussed in the following section.

Performance Potential versus Transition Probability

The mean values for performance potential, as determined from the mean values of its two assessment dimensions, Achievement and Conditions, are plotted in Figure 5.5 versus the mean values for transition probability, as determined from the mean values of its two assessment dimensions, Status and Implementability.

Figure 5.5 is divided into the same four quadrants as Figure 5.4, but the meaning of the quadrants is different. For example, Quadrant 1 is now the region of high per-

Figure 5.5
Performance versus Transition Probability (versus Figure 5.4)



RAND MG271-5.5

formance potential and high transition probability. Projects in this region were judged to be likely to achieve the required performance for their capability objectives, *independently of whether or not those capabilities were highly valued*. Thus, this figure indicates the strength of the technical approach and objectives, together with the maturity and quality of the transition plan. The distribution of the projects by quadrant is similar to that of Figure 5.4. Significant changes occur for projects with significant differences between capability and performance potential, as noted in the discussion of Figure 5.2. More specifically, we note the following changes from Figure 5.4:

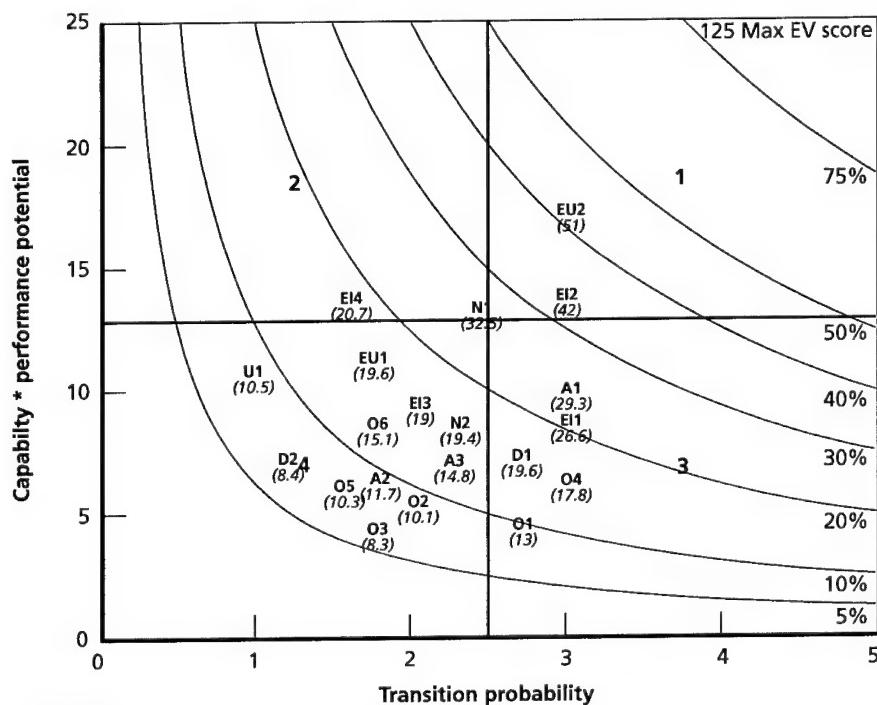
- Projects EI1 and D1 moved from Quadrant 1 to the border between Quadrants 1 and 3;
- Projects O6 and A3 moved from Quadrant 2 to the border between Quadrants 2 and 4;
- Project O5 moved from Quadrant 2 to Quadrant 4;
- Project O4 moved from Quadrant 3 to Quadrant 1; and
- Project O1 moved from Quadrant 3 to the border between Quadrants 3 and 1.

A brief glance at Figure 5.2 should be sufficient for interested readers to understand these movements. We conclude this discussion by noting that it is important to combine the results shown in Figures 5.4 and 5.5 when evaluating projects for investment. We will demonstrate this in the next section, in which, as in Figure 5.1, we use the *product* of capability and performance potential to perform a portfolio analysis.

Demonstration of a Portfolio Analysis

As discussed in the first section of this chapter, the performance potential (i.e., the performance level that would be achieved if the project were successful), *scales* the capability value that is based on achieving a required level of performance. That scaled capability is then further reduced by the transition probability in order to obtain the EV of the research, including its subsequent R&D stages and the fielding of the resulting process, component, or system. To visually capture these relationships, we plot in Figure 5.6 the *product* of the mean values of capability and performance potential versus the mean values of transition probability.

Figure 5.6
EV Portfolio Analysis by Quadrant



We divide Figure 5.6 into the same four quadrants as the previous two figures. However, in this case the quadrants have a new meaning. Quadrant 1 is now truly the high value-high transition probability quadrant, because it takes into account *both* the value of the capability and the performance potential (projects in this quadrant are aimed at a highly valued capability), and their technical approaches and objectives are consistent with achieving the required performance level for this capability. Projects EU2 and EI2 fall into this quadrant, with project N1 near its border. With the more stringent requirements of this plot, only project EI4 remains in Quadrant 2. Projects A1, EI1, D1, O4, and O1 fall into Quadrant 3, and all other projects fall into Quadrant 4.

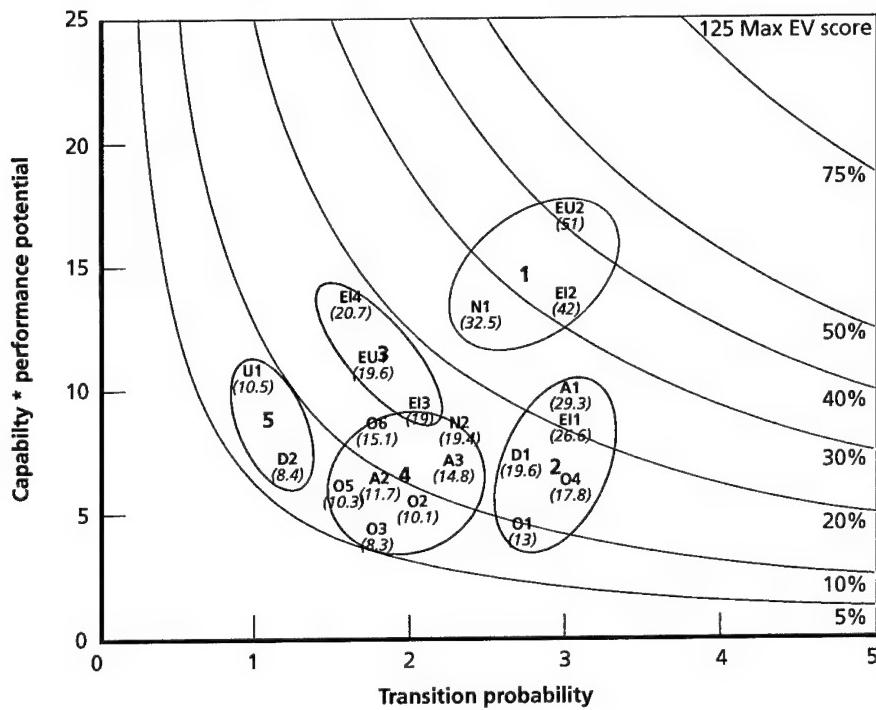
As in Figure 5.1, the EV of each project is shown in Figure 5.6 in parentheses next to its data point, as well as the EV contours, expressed in percentages of the maximum EV of 125. As noted previously, projects with similar EVs may be significantly different in character, as indicated by their position in different quadrants. For example, compare project O4 with project EI4. Their EVs differ by approximately 14 percent, yet project O4 is clearly aimed at incremental improvements in capability that were judged to be of low value, while project EI4, while its transition plan is not yet well-formed, was one of the highest valued projects, taking into account both capability and performance potential. Similar arguments could be made for projects O2 and U1, which are almost equal in EV, but vastly different in capability and performance potential.

Both the quadrant position and the EV provide us with interesting data on the projects that are useful for portfolio analysis. Taking both of these factors into account, as well as the fact that these are mean values, with uncertainty in their positions, we suggest the groupings shown in Figure 5.7 as a useful way to combine projects with similar characteristics from an investment strategy viewpoint.

Group 1 are the projects that are most likely to provide high-value capabilities that can be transitioned to use by the Navy. Group 2 are projects that are likely to be transitioned, but also likely to provide only incremental improvements in current capabilities. Group 3 are projects with the potential to provide high value capabilities but which are not likely to transition without some changes to current approaches and plans. Group 4 are projects that appear to be aimed at incremental capabilities and do not have strong transition plans. Group 5 are projects that have not yet formed their transition strategies; one of these (project U1) is aimed at a highly valued capability, while the other (project D2) is not.

The project groupings shown in Figure 5.7 are consistent with the uncertainty indicated by the spread of judgments obtained from the expert panel evaluation. Figures 5.8 through 5.12 show the mean values for each group, together with their uncertainties, using the method discussed previously. Comparing these figures, one sees that each group of projects, together with its uncertainty ranges, occupies a separate area of the (capability times performance potential) versus transition probability plot. These areas overlap only slightly, indicating that, with uncertainty taken into account, the groupings represent projects with similar characteristics. We note also, the fact that

Figure 5.7
EV Portfolio Analysis by Grouping

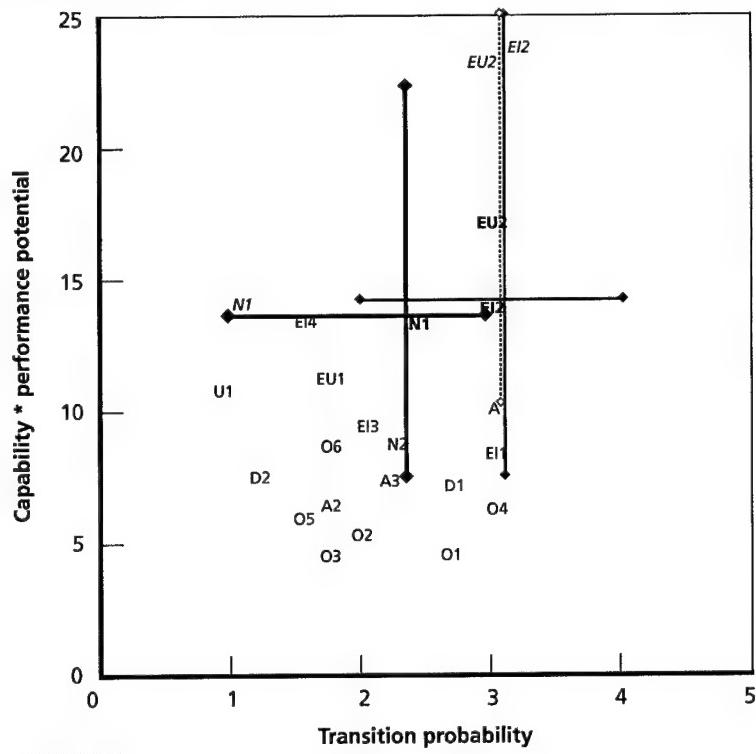


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the uncertainty range of project EI3 (Figure 5.10) includes much higher values on both axes, as compared to those of projects O6 and N2 (Figure 5.11), was the basis for assigning project EI3 to Group 3 rather than Group 4.

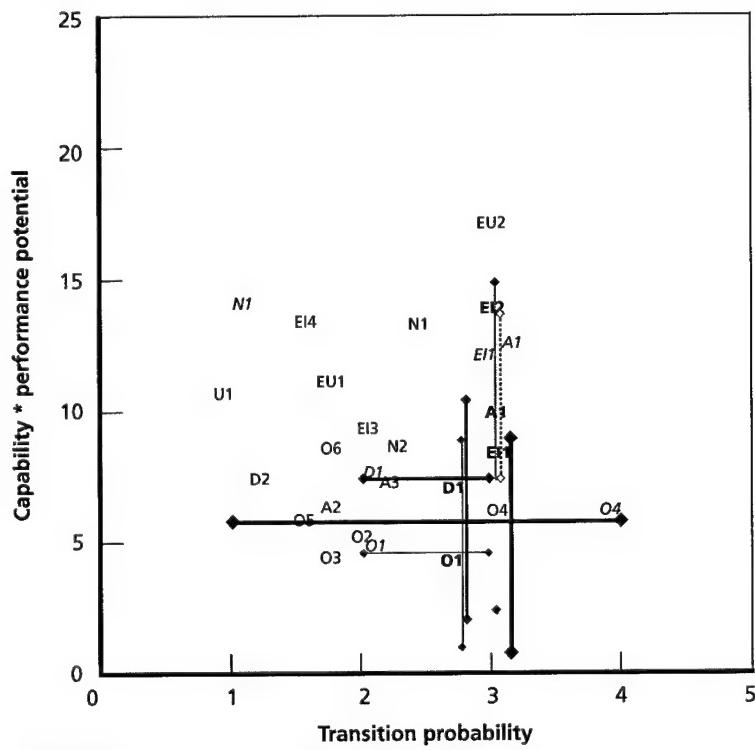
The project groupings in Figure 5.7 identify projects for which the R&D manager may have the greatest leverage. Consider, for example, the projects in Group 3, which are currently ranked relatively high in value, and in the intermediate to low range in transition probability. In order to be successful, these projects will have to develop and implement a transition plan. We posit that, absent attention by the Program Manager, the Principal Investigators may fail to do this within the time needed for a successful transition. Or, if they are not constrained sufficiently by floors on performance objectives, their tendency may be to seek out and pursue the easiest possible transition opportunities. This will increase their transition probability, but will likely happen at the expense of lowered performance objectives, which will move them toward (the incremental) Group 2. Management's job in this case is to provide the resources (e.g., staff, funds, facilities, information, coordination, planning) to overcome either of these tendencies, and push the projects toward Group 1, as opposed to Group 3, maintaining or even improving the capability and performance potential objectives, while improving the transition prospects.

Figure 5.8
Range of Uncertainty for Group 1



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Figure 5.9
Range of Uncertainty for Group 2



RAND MG271-5.9

Figure 5.10
Range of Uncertainty for Group 3

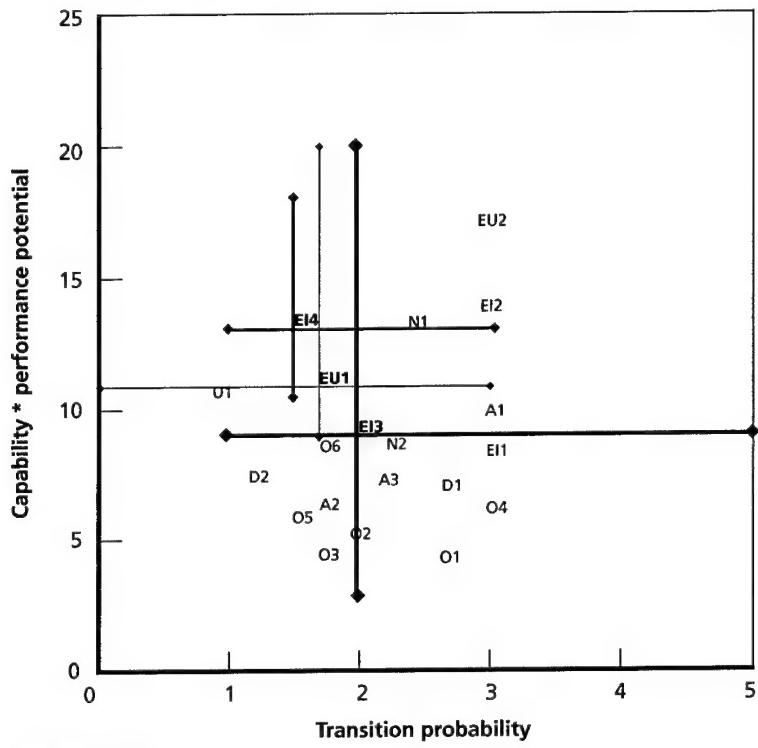


Figure 5.11
Range of Uncertainty for Group 4

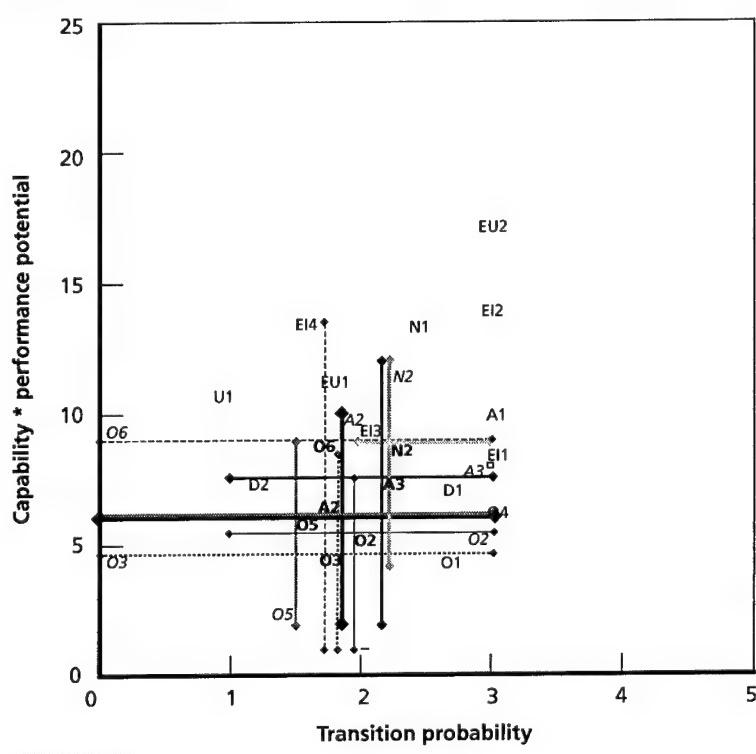
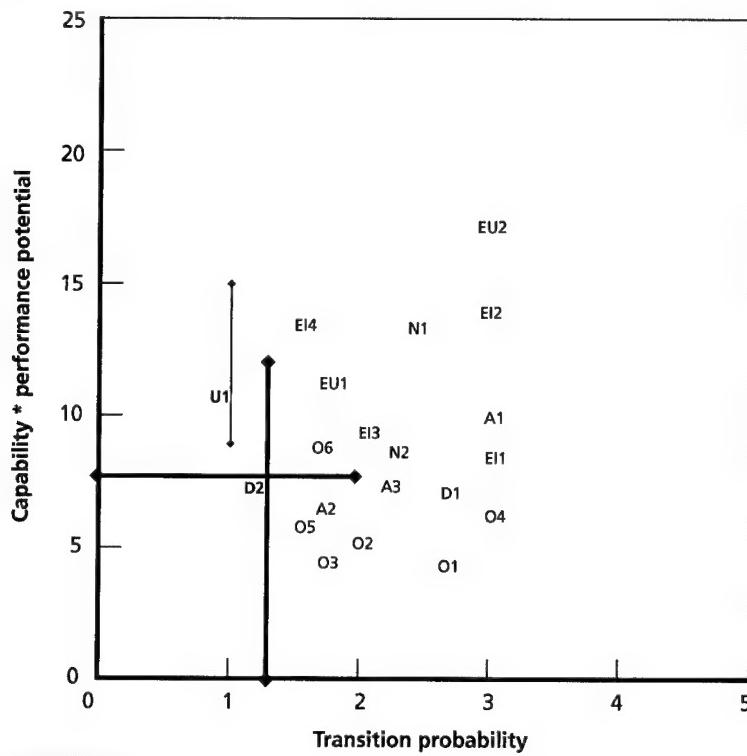


Figure 5.12
Range of Uncertainty for Group 5



This type of leverage is clearly less for the projects in Group 4, most of which are aimed at lower valued capabilities, and some of which are further along in transition planning. However, opportunities may exist for specific projects, for example, project O6, which Figures 5.2, 5.3, and 5.4 show is aimed at a highly valued capability, but with relatively low performance potential. If this project were restructured so that it might achieve the level of performance required to achieve its capability objectives, it might move to Group 3 or even Group 1.

As noted previously, the two projects in Group 5 are entirely different. Project U1 was relatively highly ranked in both capability and performance potential, but has not yet taken any steps toward transition planning. Thus, substantial leverage may exist to push this project toward Groups 3 and 1, as its transition plan begins to develop. Project D2, on the other hand, was judged to be low in all three EV dimensions. However, there was a large spread in the experts' judgments, so the management question here is why did the experts disagree, and is there a higher value component to be pursued?

We suggest the following steps when using a plot like Figure 5.7 to develop an R&D investment strategy:

1. Review the data, consider the reasons for large uncertainties and outliers, and note any effects on project positions;
2. Give a high priority to providing sufficient resources for each Group 1 project to achieve its objectives;
3. Review the transition plans of the projects in Group 2 and allocate funds based on the relative importance of their capabilities, based on user inputs;
4. Review the technical approach and objectives of the projects in Group 3, then provide the resources to develop and implement transition plans that will allow the achievement and fielding of their identified capabilities;
5. Look for additional opportunities for projects in Groups 4 and 5 that have highly valued capabilities and for which the same approach as above in 4. can be pursued.
6. Fund remaining Group 4 and Group 5 projects based on the value of their capabilities, if and only if a sound case can be made for their moving into Group 2 on a specific time frame consistent with program objectives.

As noted previously, R&D investments are made in the presence of uncertainty—uncertainty in the value of capability, uncertainty in the level of performance that the technology under investigation and other related and unrelated technologies may achieve, and uncertainty associated with transition and fielding issues. In light of these uncertainties, it is critical to a sound R&D investment strategy to periodically reconsider the analysis and decisions described in this chapter, based on the latest and best updated available data. In this sense, the S&T metric of our decision framework is the position of each project on the chart of Figure 5.7, together with its uncertainty monitored over time. As the framework is repeatedly used, and the steps above repeatedly performed, this metric, and estimates of its direction of motion, will constitute a dynamic means for maximizing the leverage of program funds to develop and transition highly valued capabilities. We note that when using this metric, it is crucial to either continue with substantially the same expert panel, or to use a control group or perform a detailed analysis of variation to ensure that changes in the evaluations result principally from changes in the projects or the requirements, and not from changes in the panel.

Conclusions and Recommendations

The objective of this project was twofold: (1) to adapt RAND's PortMan R&D portfolio analysis decision framework, which was developed for the Department of Energy (DOE), for use by the Navy; and (2) to perform a case study evaluation of a group of ONR applied research projects as a demonstration of the use of this framework. As described in the previous chapters of this report, both objectives were accomplished, with the latter using the RAND E-DEL+I Delphi-type consensus building method.

We draw the following conclusions from the work described in Chapters 1–5:

1. The adaptation of the RAND PortMan decision framework (Silbergliitt and Sherry, 2002) from civilian to military use has been accomplished, with "benefit" in the DOE version of the framework converted to "capability" for the Navy, "potential" for DOE converted to "performance potential" for the Navy, and "probability of success" for DOE converted to "transition probability" for the Navy. We note that in the version of this framework that we used for the case study evaluation, capability value was defined using a scenario approach. However, other approaches—for example, defining value in terms of mission capability packages—are possible and consistent with the framework.
2. The case study evaluation of 20 ONR Code 31 applied research (6.2) projects demonstrated the use of this framework to develop and analyze the data needed to perform an R&D portfolio analysis and develop an R&D investment strategy, including uncertainty.
3. This framework can be used with an expert group determining the values of capability, performance potential, and transition probability, including uncertainty. This was accomplished in the case study evaluation using RAND's E-DEL+I consensus building method.
4. This framework is capable of comparing and contrasting individual and groups of research projects as a function of key management variables (e.g., their potential value and status and quality of transition planning).

5. This framework provides a straightforward and logical set of repeatable steps (as described in Chapter 5), based on auditable data (e.g., developed for the case study as described in Chapter 4), to determine the expected value of research projects, together with a measure of uncertainty.
6. This framework provides a set of parameters for each research project (capability, performance potential, transition probability) that, together with measures of their uncertainties, form a metric that can be monitored over time as the framework is applied iteratively.

Based on the success of the case study evaluation, and the illustrations of its use for portfolio analysis and investment strategy development presented in Chapter 5, we recommend that ONR take the next step of demonstrating this framework on a specific project portfolio. This could take any one of several forms. One possibility might be to incorporate the framework into an existing project review process, such as that currently used by ONR Code 31, as described in Chapter 2. In this case, capability value scales would be based on a group of scenarios or mission capability packages identified in collaboration with ONR Code 31, the value determinations would be made by the existing Code 31 expert panel, and the data for the evaluation would be presentations and background material prepared by the Program Managers and Principal Investigators. The panel evaluation could follow its current open meeting consensus building approach, or use a Delphi-type consensus building method such as RAND's E-DEL+I that was used in this project. RAND would then compile the data and develop and analyze the portfolio charts shown in Chapter 5.

Another possible implementation of this decision framework might be to evaluate specific ONR project portfolios on a periodic basis by a standing expert panel (e.g., appointed to staggered three-year terms with one-third of the panel new each year). The RAND E-DEL+I consensus building method might be used to structure the panel's deliberations together with the RAND PortMan decision framework used to perform a portfolio analysis and develop an investment strategy, in a fashion similar to that described in Chapters 4 and 5.

We recommend that the data for the evaluation be background material and presentations prepared by Program Managers and Principal Investigators, but it will be critical that these materials be prepared according to specific requirements. It might also be useful to have the panel review these materials in advance of the evaluation, and identify data deficiencies that would be filled before the beginning of the evaluation.

This application of RAND's PortMan decision framework using RAND's E-DEL+I consensus-building method could be accomplished with a first round by email, and the additional rounds during a one-day or two-day meeting at which the data on capability, performance potential, and transition probability would be developed and plotted on the portfolio chart. The panel could then debate both the position of the projects on the portfolio chart and the likely direction of motion. Feedback

could be provided to the ONR Program Managers and Principal Investigators concerning where they were placed on the chart and why.

This standing panel meeting could be used as a tool to redirect funding towards the most promising projects, with the data and analysis updated at each meeting. A note of caution: successful R&D projects take time, so one would not expect to see wholesale changes in funding. Perhaps projects might be reviewed on a yearly basis, and funding changes made only after multiple unsatisfactory reviews. Such yearly reviews could enable ONR management to emphasize higher-payoff R&D, and to track progress towards achieving needed performance, as well as responding to changing requirements in a timely fashion, consistent with sound R&D management practices.

Whether it is applied to a subprogram, program, or entire class of projects (e.g., 6.2 or 6.3), RAND's PortMan decision framework can be tailored both to the scope of the evaluation and to the available resources. Projects can be evaluated in groups to achieve the desired number of individual units for the evaluation. The amount of data used in the review would then be the maximum consistent with resources available for the evaluation.

APPENDIX A**DoD Definitions of R&D Categories**

Basic Research (6.1)	Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and/or observable facts without specific applications toward processes or products in mind.
Applied Research (6.2)	Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.
Advanced Technology Development (6.3)	Includes all efforts that have moved into the development and integration of hardware for field experiments and tests.
Demonstration and Validation (6.4)	Includes all efforts necessary to evaluate integrated technologies in as realistic an operating environment as possible to assess the performance or cost reduction potential of advanced technology.
Engineering & Manufacturing Development (6.5)	Includes those projects in engineering and manufacturing development for service use but which have not received approval for full rate production.
RDT&E Management Support (6.6)	Includes R&D efforts directed toward support of installation or operations required for general R&D use. Included would be test ranges, military construction, maintenance support of laboratories, operations and maintenance of test aircraft and ships, and studies and analyses in support of R&D program.

Operational System Development (6.7)

Includes those development projects in support of development acquisition programs or upgrades still in engineering and manufacturing development, but which have received Defense Acquisition Board (DAB) or other approval for production, or for which production funds have been included in the DoD budget submission for the budget or subsequent fiscal year.

SOURCE: DOD Financial Management Regulation (Volume 2B, Chapter 5)

The Island Defense Scenario

S&T Metrics Scenario 1: Island Nation Annexation

1. *Purpose:* This scenario description supports the S&T decision process by providing a consistent basis for applying the decision framework for evaluation of a given technology. The taxonomy of capabilities, criteria for evaluation, and rules of engagement for discussion are covered in separate documents.
2. *Description:* This conflict hypothesizes a small island nation (U.S. ally) facing a large hostile neighboring nation (enemy) determined to annex the island. It includes a defensive (cruise and ballistic missile attack) and an offensive (time-critical target of opportunity) component to be considered separately. The situation is provided as context for coordinated operations involving individual units working together to achieve the defensive and offensive objectives. The effect of network-centric and/or “traditional” coordination and information sharing between units is critical to the outcome of the scenario.
3. General Context:
 - a. *Orders of Battle: Aggressor Nation.* The aggressor has asymmetric advantages over the island nation in areas of submarine warfare versus surface targets; missiles in terms of numbers and range; and electronic warfare versus the island nation’s radars. Taken together, the aggressor nation has advantages in achieving air superiority and control of Sea Lines of Communication (SLOC) early in the conflict. *U.S./island nation.* Two U.S. Carrier Battle Groups (CVBGs) are initially operating east of the island outside of enemy reach. Aegis cruisers perform ballistic defense duties off the island’s two major ports, and attack submarines (nuclear propulsion) (SSNs) are assigned to attack aggressor’s interdiction submarines. U.S. Naval air forces and command and control assets will help defeat raids across the waters between the aggressor and island nations.
 - b. *Strategic Objectives: Aggressor Nation.* Force island nation to capitulate before

U.S. intervenes. Probable intense initial attack to cut island nation SLOCs, destroy merchant vessels and infrastructure targets. Failing early capitulation, extend interdiction as a war of attrition. *U.S./island nation*. Hold out through initial attack and force a war of attrition with high enough cost to aggressor nation to force end to conflict under terms favorable to island nation. U.S. role is specifically to help island nation improve its defensive posture against missile and other attacks. No desire for U.S. to attack enemy territory. Success dependent on maintaining air superiority and control of SLOCs, as well as forcing aggressor into a defensive posture and thereby limiting its offensive options.

c. Environmental and Logistical factors:

- i. This conflict is set 10 years in the future to provide time for new technologies to develop and deploy.
- ii. Most of this scenario takes place in a littoral environment. Weather and visibility are not deemed to be factors.
- iii. The scenario assumes the U.S forces are no more than a one-day sail from the island nation at the beginning of hostilities.

4. Defensive Scenario:

- a. *Order of Battle*: Aggressor nation will attack using anti-ship cruise missiles (ASCM) and ballistic missiles; *U.S./island nation* will defend using two Aegis cruisers.
- b. *Tactical Objectives*: (assume only two U.S. Aegis cruisers involved in the area on friendly side): *Aggressor Nation*. Launch large volume of ASCMs versus U.S. and island nation targets to gain an initial tactical advantage and keep US/island nation forces on the defensive; also, launch ballistic missiles against critical island nation infrastructure targets to force early capitulation and reduce island nation logistics and command and control (C2) capability in a war of attrition. *US/island nation*. Two Aegis cruisers to defend themselves against cruise missile attacks and prevent enemy ballistic missiles from destroying key allied infrastructure targets.
- c. *Required Capabilities*: In general, one cruiser will direct its SPY-1 radar to detect and track incoming ASCMs, while another directs its SPY-1 radar to detect and track ballistic missiles. This is done so both threats are covered since this is not possible with a single radar. Within this broad assumption, the scenario has three alternatives for coordinating and dividing duties between the two Aegis cruisers: 1) “Platform-centric” operations—two cruisers act almost autonomously (e.g., no mechanism on board either ship automatically shares information on the arriving threat and/or firing solution, and no central command authority directs the defensive response). This alternative stipulates

that the ballistic missile defense ship must prioritize and service ballistic missile threats, the cruise missile defense ship must prioritize and service cruise missile threats, and both ships must be ready to decide whether to switch roles based on remaining inventories of defensive weapons; 2) Network Centric Operations—shared common operational picture (COP)—both ships can see and defend against both threats. An understanding exists between both ships concerning the nature of the attack. Each ship trains its radar exclusively on one or the other threat, but information on all threat trajectories and arrival times is shared electronically. Both ships continue to operate independently, and both ships have cruise missile and ballistic missile defense responsibilities. Coordination difficulties are likely in prioritizing and servicing the targets; 3) Network centric operations—Cooperative Engagement —both ships have access to complete defense solutions and the allocations of ships to targets is controlled centrally by one of the ships. Both good connectivity and automated systems to support real-time decision making are required. Both ships service both incoming threats.

i. High-Level Capabilities needed include:

1. Threat axis determination (intel and intelligence, surveillance, and reconnaissance [ISR])
2. Threat prioritization
3. Outer layer defense
4. Inner layer defense
5. Survivability (for self-defense component)

ii. Enabling capabilities include:

1. Connectivity
2. Secure information sharing
3. Information filtering and processing
4. Automated decision support (deconfliction, attack criteria, etc.)
5. Firing rate of friendly weapons
6. Sensor Performance Optimization

5. Offensive Scenario

- a. *Order of Battle:* Aggressor nation will face counter attack against its Kilo-class submarine by U.S. assets including a 688-class SSN, a Virginia-class SSN, and an F/A-18 armed with standard land attack missiles (SLAMs).

- b. *Tactical Objectives: Aggressor nation.* Deploy a Kilo interdiction submarine to conduct SLOC operations against allied surface targets. *U.S./island nation:* Kill the Kilo on the surface as it emerges from the harbor using a Virginia-class ISR submarine to provide real time targeting data combined with an F/A-18 armed with a SLAM-ER missile guided by global position system (GPS) and inertial navigation system (INS) systems, plus an electro-optical passive seeker.
- c. *Capabilities Required:* The primary decision to be made is whether to dispatch an F/A-18 armed with a standard land-attack missile—extended response (SLAM-ER) to attack the Kilo or leave it to the Virginia class SSN, whose torpedoes are not optimized for the water depth and which would compromise the ISR mission. Once again, three alternatives are offered with a range of connectivity and coordination: 1) Platform-centric operations—in this scenario, the ISR SSN reports up the chain of command to the operational commander who then alerts the CVBGs that a submarine has left port. No direct communications take place between the ISR SSN and the F/A-18. The Commander, Joint Task Force (CJTF), develops the attack plan and places the F/A-18 in an “alert-5” status. The F/A-18 flies out to its missile launch point under operational control of the carrier, which may abort the mission based on threat to the aircraft. The ISR SSN provides updates regarding the target through the operational chain of command, involving multiple human handoffs and communication system nodes; 2) Network Centric Operations—The ISR SSN has two-way link with the carriers through Link-16, and also provides “courtesy copies” of its communications to the operational chain of command, who may manage by exception as they watch the scenario play out. The controlling carrier uses two-way communications with the F/A-18 to control its operation and to confirm threat status updates. The F/A-18 receives some updates directly from the SSN with some latency due to security considerations. The SSN may decide based on tactical considerations (e.g., submerging target) whether to let the F/A-18 conduct the attack or to carry out the attack itself; 3) Future network-centric warfare (NCW) Operations—An uninhabited combat air vehicle (UCAV) is launched from a ship within the CVBG and acts as terminal targeter and shooter. The ISR submarine takes control of the UCAV in the final portion of the mission.
- i. The high level capabilities needed are:
1. Area of probability (AOP) determination (ISR, intel)
 2. Targeting and attack criteria decision support
 3. Reachable aim points (range and accuracy)
 4. Target neutralization

- 5. Battle damage assessment
- 6. Attacker survivability
- ii. Enabling capabilities include:
 - 1. Connectivity
 - 2. Secure information sharing
 - 3. Information filtering and processing
 - 4. Automated decision support (deconfliction, attack criteria, etc.)
 - 5. Firing rate of friendly weapons
 - 6. Sensor performance optimization

Value Descriptions and Scales

Value of S&T projects will be based on three factors:

$$\text{Value} = \text{Capability} \times \text{Performance Potential} \times \text{Transition Probability}$$

Each factor will be estimated based on answers to the following questions:

Capability

The capability that the project is aimed at achieving will be evaluated based on its importance, at a specified level of performance, to a specific warfighting scenario, as well as the extent to which it influences other important scenarios.

Assuming the project is fully successful, the resulting capability would be:

- Critical to success in the scenario
- A major factor for success in the scenario
- Helpful to success in the scenario
- Not relevant to or possibly detrimental to success in the scenario

How would you assess the applicability of this resulting capability across important scenarios?

- Pervasive across many scenarios
- Useful in a number of different scenarios
- Applicable to a very limited number of scenarios similar to this one

Performance Potential

The performance potential will be evaluated based on the extent to which the project may provide performance consistent with achieving the required capability.

Assuming the project is fully successful, the performance needed to achieve the required capability for the scenario would be:

- Fully achieved
- Partially achieved
- Hardly achieved at all

Assuming that the project is fully successful, the performance described above would be achieved under:

- All relevant scenario conditions
- Most relevant scenario conditions
- Some relevant scenario conditions
- A limited number or none of the relevant scenario conditions

Transition Probability

The transition probability will be evaluated based on the quality of the transition plan and the difficulty of remaining technical and fielding problems.

The project and project team is presently characterized as:

- No remaining technical problems; experience fielding similar technology
- Remaining technical problems; experience fielding similar technology
- No remaining technical problems; no experience fielding similar technology
- Remaining technical problems; no experience fielding similar technology

The transition plan for this project is:

- Well conceived and appears to be implementable
- Has some problems with cost, schedule, or other fielding burdens
- Has major problems with cost, schedule, or other fielding burdens
- Is severely flawed or nonexistent

Capability Scale

	Pervasive	Number of Different	Limited Number
Critical	5	4	3
Major Factor	4.5	3.5	2.5
Helpful	4	3	2
Not Relevant	3	2.5	1

Performance Potential Scale

	Fully	Partially	Hardly At All
All	5	4	2.5
Most	4	3	2
Some	3	2.5	1
Limited or None	2	1	0

Transition Probability Scale

	No Technical Problems Experience Fielding	No Technical Problems No Experience Fielding or Technical Problems Experience Fielding	Technical Problems No Experience Fielding
Implementable	5	4	3
Some Problems	4	3	2
Major Problems	3	2	1
Severely Flawed	2	1	0

APPENDIX D

Project Summary Format

Project Title

Overview

A brief summary of the project background and objectives, including the following:

- the goal for the operational capability of the project;
- who is going to use it or benefit from it; and
- what is being proposed.

Capability

Description of the operational capability that is being sought through R&D, who is going to use it, and why it is needed.

Performance Potential

Description of the level of performance that is being sought through R&D, and the conditions under which the performance will be achieved, for example:

- savings in some combination of time (e.g., time-to-attack), quality (e.g., of data), and cost (e.g., operational cost, acquisition cost, maintenance cost); or
- improvement over performance of an existing system by specific amount.

Transition Probability

Technical Approach Description of the technical approach to achieving the objectives, including discussion of the current state-of-the-art and how it will be improved by the R&D, and the current status of the research.

Experience Fielding Description of any experience of members of the project team with fielding similar capabilities or technologies.

Transition Plan Description of the intended transition targets and the plan for accomplishing transition of the capability to development and fielding, including current status.

APPENDIX E

Project Overviews

Alternative Human-Machine Interface Project 1 (A1)

This project will design, develop, and assess an integrated 3D visualization command system as a tactical aid for the anti-submarine warfare decisionmaker. The current research focus is on developing, in a laboratory environment, an upgraded prototype data processor to submarines' fielded tactical control systems and associated sensor databases. Creating a reliable and consistent common tactical picture across platforms is a major challenge to achieving net-centric "speed of command" in the multiwarfare environment; decision-makers have traditionally assimilated data from multiple 2D displays and paper plots.

Alternative Human-Machine Interface Project 2 (A2)

The submarine commander's access and ability to use correct tactical information, including understanding uncertainty in measurements, is one of the major factors in achieving success in the battlespace. However, in most cases the visualizations do not account for uncertainty, contrary to the assumption of users. Acoustic detection and tracking of targets is an area in which visualizations could benefit from uncertainty information. The accuracy of sonar depends on uncertainty associated with environmental features. Having the ability to represent uncertainty in the target's depth has the potential to convey a more complete Common Tactical Picture (CTP). Using this added knowledge, the warfighter may be able to leverage his improved understanding into tactical decisions that are made more quickly and are of higher quality than those of his adversary.

Alternative Human-Machine Interface Project 3 (A3)

Existing visualization systems are awkward and provide limited interaction capabilities. Multimodal interaction, allowing speech and 3D gesturing can help make these

systems powerful adjuncts to other command and control systems. In addition, this project will create a parameterization scheme to enable a developer to create a multi-modal system for their desired 2D or 3D military application rapidly.

Distributed Sensor Fleet Project 1 (D1)

This project is providing for the real-time allocation and platform assignment of radar resources to perform detection, track and missile support functions for Antiaircraft Warfare (AAW) and Theater Ballistic Defense missions. The ability to replace hard coded limitations on sensor utilization with dynamically adjusted data service rates and sensor assignments in response to the tactical situation is expected to improve single ship and coordinated warfighting capabilities.

Distributed Sensor Fleet Project 2 (D2)

A communication system at a sensor location that actively transmits has a large number of constraints. The complete assembly will be large and the power source for the system presents limitations in endurance and increases in cost. The proposed system concept is to obtain sensor information from the data source by utilizing passive radio frequency (RF) tag technology. The technology allows for significant cost savings and reduced size.

Expeditionary Communications Infrastructure Project 1 (EI1)

This project is a broad-based program focused on developing technology applications to achieve the potential for an interoperable, manageable, and secure military internetwork built overtop various military and civil subnetworks, based on current and emerging standards and commercial-off-the-shelf software. The objective is to design, implement and demonstrate a common technical architecture for interoperable secure networks and intended to lead towards a basis for a robust interoperability specification. EI1 is related with EI2 and EI3.

Expeditionary Communications Infrastructure Project 2 (EI2)

Commercial Internet today primarily relies on Internet Protocol version 4 (IPv4) networking protocols, yet a developing standard, Internet Protocol version 6 (IPv6), is seen as a far more robust and capable successor to the current technology, but suffers significantly from a lack of compatibility in supporting current systems. IPv6 addresses a number of IPv4 problem issues and also provides new opportunities for

system and protocol designers. This project intends to carefully look at the myriad of technical and architectural options for integrating emerging IPv6 products and new routing products through the lens of the current Automated Digital Network System (ADNS), which is presently based on IPv4. In addition to exploring future solutions, plans are to address existing networking problems and shortfalls by capitalizing on the enhanced capabilities of IPv6 technology. Findings from this project should have some influence on the direction and implementation of a larger parent program.

Expeditionary Communications Infrastructure Project 3 (EI3)

This project will support the development and implementation of a mobile, wireless, communication architecture that will be capable of supporting a multinational coalition in a tactical environment. The focus will be on integrating emerging mobile networking technologies into a demonstration system that can meet operational requirements. The military's future demands will likely surpass those of commercial systems that rely on fixed, pre-positioned infrastructure and looser quality of service (QoS) definitions. This proposal is intended to provide momentum and act as a subtask for a significant element of the planned Expeditionary Communications Infrastructure Project 1.

Expeditionary Communications Infrastructure Project 4 (EI4)

All branches of the American military are moving rapidly toward network centric architectures for voice, video, and data communications. The major effort of this project will be to develop an asymmetric secure link through the Joint Tactical Radio System (JTRS) framework to provide network access to vulnerable assets.

Expeditionary Communications Upgrade Project 1 (EU1)

Networking protocols will be developed under this R&D program that will enable mobile, tactical, wireless networking with directional antennas. This is an area where very little research had been done prior to the start of this ONR program in Fiscal Year 2000 most existing wireless mobile networks use omni-directional antennas. The current focus is on systems that interface to Defense Information System Network (DISN)-like data networks and protocol suites rather than systems for which timing constraints are intimately tied to threat-object tracking and weapons delivery (such as the Cooperative Engagement Processor, or CEP).

Expeditionary Communications Upgrade Project 2 (EU2)

This technology will offer the warfighter a significant advantage in the ultrahigh frequency (UHF) transfer of video, voice, and target data for improved command and control, including but not limited to control/data transfer for Unmanned Aerial Vehicle programs.

Network/Information Infrastructure Project 1 (N1)

To achieve the high levels of situational awareness and shared knowledge among all elements of a joint force, warfighters must be able to gain access to all relevant data from heterogeneous sources, assess its credibility, and respond to the critical changes in a meaningful manner. The project team proposes to provide an active capability, implemented in the form of software tools, to assist operationally in the integration, filtering, fusing, validating, and monitoring of information from distributed fleets of heterogeneous sources such as sensors, platforms, and networks.

Network/Information Infrastructure Project 2 (N2)

Future swarms of network-centric combat systems will increasingly run unobtrusively and autonomously, shielding Naval operators from unnecessary details, while communicating and responding to mission-critical information at an accelerated operational tempo. In such an environment, it becomes very difficult to predict system/package configurations or workloads in advance.

Technologies are thus being developed to bridge the gap between military applications and the underlying operating systems and communication software in order to provide the critically-important capability of reusable, reliable services on which network-centric warfare must depend. This program composites two related projects.

Optimization or Decision-Aid Project 1 (O1)

This tool will provide a rapid, probabilistic method for predicting course of action development in time critical targeting. This tool serves as a Battlespace Decision Aid to assist the mission planner in assessing potential locations of mobile threats as well as providing mobile target identification. The software is a predictive modeling and analysis software tool that integrates mature, commercial-off-the-shelf technology with advanced Navy-specific tools that blend imagery, spatial features, elevation, terrain, with real-time tactical feeds and geopolitical tendency models. This tool will operate as a network-based software resource.

Optimization or Decision-Aid Project 2 (O2)

This project will investigate the efficacy of enhancing the ability to defend against anti-ship cruise missiles and other airborne threats by providing simulation tools that assist in predicting and assessing the performance of AAW systems for single platforms and battlegroups. The goal of this project is to help decide where best to place and configure sensors and weapon platforms to maximize coverage, given a set of AAW-capable ships and a task of defending an area from air threats.

Optimization or Decision-Aid Project 3 (O3)

The objective of this project is to create a computerized planner to: choose land attack missions; allocate weapons to meet the tasking requirements as closely as possible; simultaneously consider factors such as retaining maximal follow-on firing capability and leveling missile inventory across designated platforms.

Optimization or Decision-Aid Project 4 (O4)

Scheduled shipboard resources have varying requirements for accomplishing certain processing tasks. The inherent problem of reserving machine service times for customers (e.g., targets) appearing in the queue is a generic problem that may be able to be solved using one scheduling optimization algorithm.

Optimization or Decision-Aid Project 5 (O5)

Course of Action replanning, a complex activity, is invariably required during combat and could be supported by software tools. However, existing decision aids for crisis-action planning do not address this need. A planner must manually review disjoint information sources to gather and synthesize this information, and identify those events that are critical for monitoring.

Optimization or Decision-Aid Project 6 (O6)

A dynamic approach is demonstrated for achieving the real-time and integrated deconfliction of scheduled fires while meeting required on-target ordnance delivery rates. This decision aid will provide operators with a new awareness of the impact of their fires and will increase the safety to non-hostiles in the theater while decreasing the fratricide risk. The deconfliction technology begins to open the door for evolving joint

missile and air-engagement zones and allows the greater defense and strike power from smaller forces.

UAV General Research Project 1 (U1)

Tactical military usage of unmanned systems for operations is anticipated to become increasingly prevalent and influential in future naval operations. This emerging application has both high visibility and high uncertainty due to the larger-scale reliance on networked performance and abstraction on the part of the warfighters. The military application of unmanned systems to Littoral Warfare is a natural extension of a much larger technological trend in automation, standardization, and modularization. This project effectively functions as a portfolio of related projects with a number of tasks under direct management and as well oversees related work.

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